# US-Japan Collaborative Research on Evaluation Tools and Methods

## Comparison of Evaluation Tools and Methods Used in the United States (U.S.) and Japan

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**Final Report — April 2016**
**Publication Number: FHWA-JPO-16-326**

U.S. Department of Transportation

MLIT
Ministry of Land, Infrastructure, Transport and Tourism

Produced by Noblis, Inc.
U.S. Department of Transportation
ITS Joint Program Office

# Notice

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FHWA-JPO-16-326 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| US-Japan Collaborative Research on Evaluation Tools and Methods: Comparison of Evaluation Tools and Methods Used in the United States (U.S.) and Japan | April 2016 |
| | 6. Performing Organization Code |
| 7. Author(s)<br>Meenakshy Vasudevan, Kathy Thompson, Amy Jacobi, Michael Mercer, Michael Brooks, Stephanie Lawrence and Daniel Vickery, Koichi Sakai, Ryoichi Watanabe, Hideyuki Kanoshima, Shingo Mawatari and Takahiro Tsukiji, Eli Machek, and Dale Thompson | 8. Performing Organization Report No. |
| 9. Performing Organization Name And Address<br>Noblis, Inc., 600 Maryland Ave, SW, Suite 755, Washington, DC 20024<br><br>National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism, Japan | 10. Work Unit No. (TRAIS) |
| | 11. Contract or Grant No.<br>DTFH61-11-D-00018 |
| 12. Sponsoring Agency Name and Address<br>ITS-Joint Program Office, U.S. DOT<br>1200 New Jersey Avenue, S.E. Washington, DC 20590 | 13. Type of Report and Period Covered |
| | 14. Sponsoring Agency Code |

**15. Supplementary Notes**
Work Performed for: Dale Thompson (FHWA, Task Manager); Gene McHale (FHWA); Marcia Pincus (ITS JPO)


**16. Abstract**

The United States (U.S.) and Japan have similar transportation challenges, and share a common belief that cooperative systems can deliver significant societal benefits for road users, especially in terms of safer, more energy-efficient, and environmentally friendly surface transportation. The two regions recognize that coordinated research can reduce costs and accelerate the development, deployment, and adoption of cooperative systems. The report is an outcome of the U.S.-Japan bi-lateral collaborative research on evaluation tools and methods. The report includes:

- Case studies of cost-benefit evaluations, including performance indicators, and measurement methods, of Intelligent Transportation Systems (ITS) and cooperative systems in the U.S. and Japan
- Comparison and assessment of existing evaluation methods used for evaluating ITS and cooperative systems in the U.S. and Japan
- Consistent glossary of terms for evaluations for use in the U.S. and Japan
- Consistent categorization and organization of performance indicators and measurement methods

The following are the key lessons learned from the assessment:

- Evaluations should be performed by an independent party who has no vested interest or stake in the project itself to eliminate potential bias.
- More rigorous experimental design is needed to better isolate benefits of cooperative systems or ITS implementations
- Consistent dollar values should be applied when monetizing benefits.
- Acceptance of cooperative systems based on short-term exposures can be misleading.
- Longer-term impact of cooperative systems should be examined prior to large scale deployment.

The following are some opportunities for future collaboration between the U.S. and Japan, including:

- Development of consistent methodology for evaluations
- Application of the consistent methodology to evaluate a cooperative system deployment, either in the U.S. or in Japan (or one each in both nations)


| 17. Key Words | 18. Distribution Statement |
|---|---|
| Cooperative systems, connected vehicles, probe system, evaluation, cost-benefit, performance measures, indicators | |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 161 | |

**Form DOT F 1700.7 (8-72)** **Reproduction of completed page authorized**

# Acknowledgements

This is a joint product of the USDOT and MLIT.

The authors wish to acknowledge several contributors to this study:

James Pol (FHWA), Gene McHale (FHWA), and Jane Lappin (Volpe), for their review and comments.

Sponsors of the Noblis Task: James Pol (FHWA) and Marcia Pincus (ITS JPO), for their support.

Masayuki Kannan (MLIT), Hiroshi Makino (MLIT/NILIM), for their review and comments.

# Table of Contents

# List of Figures

# List of Tables

# Preface

The purpose of this report is to give the reader an overview of the cost-benefit evaluations of Intelligent Transportation Systems (ITS) and cooperative systems conducted in the U.S. and Japan. This document also compares the definitions and measurement methods of performance indicators and evaluation approaches used in the U.S. and Japan.

The intended audience for this report is a transportation professional who is embarking on evaluations of cooperative systems and is interested in understanding the common challenges and issues with different types of evaluation methods.

For a high-level summary comparison and lessons learned, the reader should read Section 7. For an overview of the ITS and cooperative system evaluations conducted in the U.S. and Japan, the reader should refer to Section 5. For an in depth treatment of these evaluations, the reader should refer to the relevant evaluation reports referenced in Section 5.

# Executive Summary

## Background

The United States (U.S.) and Japan have similar transportation challenges, and share a common belief that cooperative systems (such as connected vehicle systems, probe data systems, etc.) can deliver significant societal benefits for road users. Cooperative systems based on Intelligent Transportation System (ITS) technologies can deliver significant benefits for all road users and the public, especially in terms of safer, more energy-efficient, and environmentally friendly surface transportation. Through a wireless communications network, a cooperative system enables cars, buses, trucks, and other vehicles to “talk” to each other and to roadside infrastructure, cell phones, and other devices, exchanging safety, mobility, and environmental information. The two regions recognize that coordinated research can reduce costs and accelerate the development, deployment, and adoption of cooperative systems.

The U.S. Department of Transportation (U.S. DOT) and the Road Bureau of the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT) have a long history of sharing information on ITS activities, including an annual U.S.-Japan ITS Workshop held in conjunction with the ITS World Congress. In order to formalize bilateral cooperation and exchange of information on Intelligent Transportation Systems (ITS), especially on Cooperative Systems, a memorandum of cooperation was signed between the U.S. Department of Transportation (U.S. DOT) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan in October 2010. The agencies formed a U.S.-Japan ITS Task Force to exchange information and identify the areas for collaborative research to foster the development and deployment of Cooperative Systems in both the U.S. and Japan. The U.S.-Japan Task Force identified the following high-priority areas for conducting collaborative research and sharing information: (i) international standards harmonization, (ii) evaluation tools and methods, (iii) probe data, and (iv) automation in road transport. The expected outcomes of a bi-lateral U.S.-Japan collaboration include:

- Expedited or immediate transferability of lessons learned between nations
- Significant cost savings through shared experiences and collaborative research
- Preclusion of development and adoption of redundant standards
- Accelerated deployment and adoption of cooperative systems
- Global marketability of products due to consistency and compatibility of data, cooperative systems, technology, and practices, and harmonization of standards
- Sustained global competitiveness for auto manufacturers and device makers

This report is an outcome of the US-Japan collaboration in “evaluation tools and methods” high-priority area.

# Purpose

To encourage the adoption and deployment of cooperative systems by the public and private (e.g., Original Equipment Manufacturers) sectors, it is essential to demonstrate the value of these systems. Although methods and tools have been developed for evaluating and determining quantitative and qualitative value of ITS, no common methodology exists which can be applied consistently across evaluation efforts within the U.S. or within Japan. Secondly, evaluation terminologies are used inconsistently, varying not only by nation, but by agency or project. Finally, methods for measuring and monetizing benefits are applied inconsistently.

Thus, although ITS evaluations have been conducted since the deployment of such systems, there is no common approach to evaluating ITS systems. This makes it difficult to compare systems with diverse capabilities deployed in diverse parts of the nation, resulting in lack of confidence among public and private sector stakeholders in the results or the demonstrated value of the systems. Bi-lateral collaborative research on evaluation tools and methods is a step towards improving collective awareness of evaluation approaches, and reducing inconsistencies in the usage of evaluation terminologies as well as evaluations of cooperative systems.

The purpose of bi-lateral collaborative research on evaluation tools and methods is to:

- Share case studies of cost-benefit evaluations, including performance indicators, and measurement methods, of Intelligent Transportation Systems (ITS) and cooperative systems in the U.S. and Japan
- Compare and assess existing evaluation methods used for evaluating ITS and cooperative systems in the U.S. and Japan
- Develop a consistent glossary of terms for evaluations for use in the U.S. and Japan
- Develop consistent categorization and organization of performance indicators and measurement methods
- Work towards a consistent methodology to evaluate the performance and cost-benefit of cooperative systems and applications

The report documents U.S. and Japan's collaborative effort in achieving the above stated purpose with the exception of the consistent methodology for evaluations, which may be developed as part of a future collaboration between U.S. and Japan.

# Approach

Researchers from Noblis (on behalf of U.S. DOT) and MLIT summarized the approaches adopted in in field tests and analysis, modeling, and simulation (AMS) evaluations of ITS and cooperative systems in the U.S and Japan (see Section 5). These evaluations examined safety, mobility, and sustainability benefits of cooperative and ITS systems.

In the U.S., the review covered a range of evaluation approaches, including field operational tests, evaluations of pilot demonstrations and small-scale field tests, and AMS-based evaluations:

- Evaluations of two major ITS programs that have adopted U.S. DOT's logic model approach (described in 5.1.1)

    - Urban Partnership Agreement (UPA)/Congestion Reduction Demonstration (CRD) Projects in Minnesota, Atlanta, Miami, Seattle, San Francisco, and Los Angeles
    - Integrated Corridor Management (ICM) deployments in Dallas, TX, and San Diego, CA
- Field operational tests (FOTs) and evaluations of field demonstrations that were conducted to assess the performance of connected vehicle technologies:
    - Automotive Collision Avoidance System (ACAS) FOT
    - Integrated Vehicle-Based Safety Systems (IVBSS) FOT
    - Preliminary Assessments of two Vehicle-to-Vehicle (V2V) arterial safety applications (Intersection Movement Assist (IMA) and Left Turn Assist (LTA)) that were deployed and testing during the Safety Pilot Model Deployment in Ann Arbor, Michigan
    - Impacts assessment of small-scale demonstrations of connected vehicle applications that focus primarily on improving system and traveler mobility:
        - Intelligent Network Flow Optimization (INFLO)
        - Multi-modal Intelligent Traffic Signal Systems (MMITSS)
        - Response, Emergency Staging and Communications, Uniform Management and Evacuation (R.E.S.C.U.M.E)
- Analytical studies that assessed the benefits of ITS or connected vehicle technologies:
    - Analysis, modeling, and simulation (AMS) efforts that assessed the benefits of ICM in a simulation environment:
        - ICM AMS Dallas
        - ICM AMS San Diego
    - Benefit-Cost Analysis of Vehicle-Infrastructure Integration (VII)
    - Analysis, modeling, and simulation (AMS) efforts that assessed the benefits of connected vehicle applications that focus primarily on reducing negative environmental impacts:
        - Eco-Signal Operations
        - Eco-Lanes
        - Low Emissions Zones

In Japan, the reviews were mostly focused on evaluations of FOTs:

- FOTS were conducted to assess the performance of several cooperative system-enabled driver assistance technologies:
    - Traffic Smoother Service
    - Sharp  Curve Warning
    - Vertical Curve Warning
    - Merging Assistance
    - Curve Speed Warning
    - Signal missing/collision prevention support system
    - Stop regulation missing/ crossing collision prevention support system
    - Advanced Safety Vehicle (ASV) technology for accident reduction

The report also identifies the key performance indicators used in the U.S. and Japan, and methods for measuring them (Section 6).  A glossary of terms is included in the Appendix.

# Summary Assessment

- Evaluations in the U.S. were mostly conducted by an independent evaluator as evaluations of pilot demonstrations and small-scale field tests, and AMS-based evaluations, whereas in Japan evaluations were mostly conducted as FOTs.
- Very few evaluations examined the longer-range impacts of cooperative systems.
- There was limited discussion on how lack of driver behaviors in the presence of cooperative systems was incorporated in the impacts assessment.
- Neither the U.S. nor Japan applied rigorous experimental designs to isolate impacts of multiple services or applications.
- There is a lack of common definitions for performance measures and methods for estimating them, between the U.S. and Japan.

# Lessons Learned

The following are the key lessons learned from the assessment:

- **Evaluations should be performed by an independent party who has no vested interest or stake in the project itself to eliminate potential bias.** An evaluation of a project or a program is essential to discover how well the project or program is able to attain its goals. An independent evaluation by a third party who has no vested interest or stake in the project will eliminate bias in the findings. An independent evaluation can help inform the U.S. DOT or MLIT if their investments were able to achieve the project or program goals; of the lessons that can be used to improve the continued operation of the cooperative system as well as the design of future projects; and of how resources should be applied in the future.
- **More rigorous experimental design is needed to better isolate benefits of cooperative systems or ITS implementations**. The review revealed that most of the evaluation efforts were challenged by their inability to isolate the impacts of the connected vehicle or ITS implementations from those of exogenous factors or competing projects. For example, in Minnesota, U.S., multiple projects with overlapping benefits were underway simultaneously making it difficult to isolate the benefits of the UPA/CRD projects. Secondly, exogenous factors, such as rising gas prices, unemployment, etc., made it difficult to determine the effectiveness of the UPA/CRD projects. A good experimental design can minimize impacts of exogenous or confounding factors. One approach to solving this issue is by identifying control (without) and treatment (with) groups that experience the same or similar exogenous factors.
- **Consistent dollar values should be applied when monetizing benefits**. There are inconsistencies in the valuation of benefits across programs and across projects even within the same national evaluation program. In the U.S., the UPA/CRD San Francisco project used the value of time for travelers and truck drivers from 2000, while the UPA/CRD Minnesota and Atlanta projects used the revised value of time from 2009 ($12.50). The ICM AMS Dallas effort used $12.00 as the value of time, while the ICM AMS San Diego effort used $24.00. Neither of the two efforts used the recommended value of traveler time, which is $12.50 based on the revised valuation of travel time issued by U.S. DOT. Most up to date U.S. DOT guidance on valuation of benefits should be used across all evaluation projects in the U.S. Any deviations and reasons for

deviation should be noted in the evaluation plans. A similar approach should also be used in Japan.

- **Acceptance of cooperative systems based on short-term exposures can be misleading.** As cooperative systems are in their infancy, minimal data exist. There is lack of information or behavioral theory regarding how drivers would respond to warnings from cooperative systems, especially if multiple warnings are generated due to detection of multiple threats. Large FOT investments will benefit from comparable investment in data collection, storage, and analytics. Small scale FOTs should be supplemented by additional FOTs, small-scale demonstrations, and/or analytical studies.
- **Longer-term impact of cooperative systems should be examined prior to large scale deployment.** Prior to deploying cooperative systems on a large scale, it is essential to assess the robustness, effectiveness, usability, and acceptance of the systems as tested as well as projected over time and geographic scope, and for varying market adoption rates of application and driver compliance rates. For example, testing of different road side equipment (e.g., ITS Spot units) deployment densities should be examined to assess at what point there is diminishing marginal returns. Such longer-term impacts assessments may necessitate the use of analytical tools or techniques.

# Conclusions and Opportunities for Future Collaboration

The report is an outcome of the U.S.-Japan bi-lateral collaborative research on evaluation tools and methods. The report includes:

- Case studies of cost-benefit evaluations, including performance indicators, and measurement methods, of Intelligent Transportation Systems (ITS) and cooperative systems in the U.S. and Japan
- Comparison and assessment of existing evaluation methods used for evaluating ITS and cooperative systems in the U.S. and Japan
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The following are some opportunities for future collaboration between the U.S. and Japan, including:

- Development of consistent methodology for evaluations
- Application of the consistent methodology to evaluate a cooperative system deployment, either in the U.S. or in Japan (or one each in both nations)

# 1 Introduction

The United States (U.S.) and Japan have similar transportation challenges, and share a common belief that cooperative systems (such as connected vehicle systems, probe data systems, etc.) can deliver significant societal benefits for road users. Cooperative systems based on Intelligent Transportation System (ITS) technologies can deliver significant benefits for all road users and the public, especially in terms of safer, more energy-efficient, and environmentally friendly surface transportation. Through a wireless communications network, a cooperative system enables cars, buses, trucks, and other vehicles to "talk" to each other and to roadside infrastructure, cell phones, and other devices, exchanging safety, mobility, and environmental information. The two regions recognize that coordinated research can reduce costs and accelerate the development, deployment, and adoption of cooperative systems.

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This report is part of the collaborative research effort in the "evaluation tools and methods" high-priority area. The report is organized as follows. The research purpose, outcomes, and scope are presented in Sections 2 to 4, respectively. Section 5.1. presents U.S. and Japan's philosophical approaches for ITS evaluation. Section 5.2 summarizes the evaluation approaches adopted in the U.S. and Japan, through case studies. Section 6 summarizes the performance measures identified during this collaborative effort, their definitions, and measurement methods in a table format. Section 7 provides a summary assessment of the evaluation approaches discussed in Section 5, and performance measures and their measurement methods discussed in Section 6. This section also identifies the lessons learned with respect to evaluations. Finally, conclusions and opportunities for future collaboration are presented in Section 8.

# 2 Research Purpose

To encourage the adoption and deployment of cooperative systems by the public and private (e.g., Original Equipment Manufacturers) sectors, it is essential to demonstrate the value of these systems. Although methods and tools have been developed for evaluating and determining quantitative and qualitative value of ITS, no common methodology exists which can be applied consistently across evaluation efforts within the U.S. or within Japan. Secondly, evaluation terminologies are used inconsistently, varying not only by nation, but by agency or project. Finally, methods for measuring and monetizing benefits are applied inconsistently.

Thus, although ITS evaluations have been conducted since the deployment of such systems, there is no common approach to evaluating ITS systems. This makes it difficult to compare systems with diverse capabilities deployed in diverse parts of the nation, resulting in lack of confidence among public and private sector stakeholders in the results or the demonstrated value of the systems. Bi-lateral collaborative research on evaluation tools and methods is a step towards improving collective awareness of evaluation approaches, and reducing inconsistencies in the usage of evaluation terminologies as well as evaluations of cooperative systems.

The purpose of a bi-lateral collaborative research on evaluation tools and methods is to:

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- Develop a consistent glossary of terms for evaluations for use in the U.S. and Japan
- Develop consistent categorization and organization of performance indicators and measurement methods
- Work towards a consistent methodology to evaluate the performance and cost-benefit of cooperative systems and applications

This report will summarize and compare the evaluations methods and tools used in the U.S. and Japan.

# 3 Research Outcomes

The expected outcomes from this report include:

- Increased understanding of existing evaluation methods used in the U.S. and Japan, and their applicability for testing ITS and cooperative vehicle systems;
- Insight into challenges and issues with different types of evaluation methods; and
- Reduced cost for testing of ITS and cooperative vehicle applications through documented experiences, challenges, and lessons learned.

# 4 Research Scope

The collaborative research effort documented in this report focuses only on evaluations of applications of interest to the U.S. and Japan as well as evaluations of noteworthy ITS deployments and cooperative system demonstrations and field operational tests conducted in the U.S and Japan. The report presents a snapshot of how evaluation is performed in the U.S. and Japan. It is expected that evaluation approaches will evolve with development of newer technologies and applications, and insights and lessons learned from past evaluation efforts.

# 5 Summary of Evaluation Tools and Methods in the U.S. and Japan

This section presents U.S. and Japan's philosophical approaches for ITS evaluation. This section also summarizes the evaluation approaches adopted in the U.S. and Japan, through case studies.

## 5.1 ITS Evaluation Philosophical Approach

### 5.1.1 U.S. Approach

The U.S. DOT has been using the logic model as a standard approach for evaluating ITS Programs. A logic model describes the relationship between program resources, planned activities, and expected results through a series of statements that link program components (inputs, activities, outputs and outcomes) in a chain of causality. The logic model provides a conceptual framework for evaluating a program, including expectations, organization of the work, and evaluation. The model explicitly recognizes that the ultimate successes or shortcomings of a technology deployment are the end results of a long series of interdependent events and conditions (causes and effects), and stresses a step-wise approach in which each link in the cause-effect chain is investigated in the evaluation.

The example (Figure 5-1) below shows the basic structure for a logic model. The structure should be tailored to meet the evaluation needs of specific projects or programs.


**Figure 5-1: Basic Logic Model Structure (*Source: Adapted from W.K. Kellogg Foundation Logic Model Development Guide, W.K. Kellogg Foundation, Battle Creek, Michigan. 2004. [1]*)**

#### *5.1.1.1 Developing a Logic Model*

A logic model may be developed by adopting the approach detailed below:

Step 1: Clarify program goals and define elements of the program in a table

- *Situation*: Describes the problem and the challenges
- *Purpose*: Broad statement of need
- *Goals*: Describes the changes that will be produced through the program
- *Inputs*: Represents investments (hardware, software, infrastructure, staff hires, training, development or revision of policies or procedures, memoranda of understanding, etc.)
- *Outputs*: Describes how investments are utilized, the capabilities they provide, and how those capabilities are used (e.g., outputs that reflect operators' utilization of the

investments to provide road weather advisories; direct outputs of technology systems, such as the improvement in data collected through new or enhanced sensors)

- *Outcomes*: Describes the short-term, medium-term, and long-term impacts of the investments (e.g., decrease in hard-braking → decrease in emissions →reduction in pollution-related illnesses)
- *Assumptions*: Represents assumptions used in the program
- *External Factors*: Identifies external factors that might positively or negatively influence the outcomes of the program

Step 2: Verify logic table with stakeholders
Step 3: Develop logic model diagram and describe cause-effect links
Step 4: Verify logic model with stakeholders

Figure 5-2 presents a logic model diagram with cause-effect links developed for the Safe Routes to School program.

#### *5.1.1.2 Benefits of Logic Models*

The key benefits of using a logic model approach to evaluate a project or program are that it:

- Illustrates the logic or theory of the program or project,
- Focuses attention on the most important connections between actions and results,
- Builds a common understanding among staff and with stakeholders,
- Establish a framework for measurement and evaluation, and
- Finds "gaps" in the logic of a program and works to resolve them.

#### *5.1.1.3 Limitations of Logic Models*

The key limitations of using a logic model approach to evaluate a project or program are that it:

- Represents reality, but it is not reality;
- Fails to reflect/capture the complexity of some programs, due to its linear nature;
- Can over simplify a program;
- Has questionable causal attribution (i.e., does not prove the program caused the observed outcome); and
- Does not reflect unintended outcomes (positive or negative)

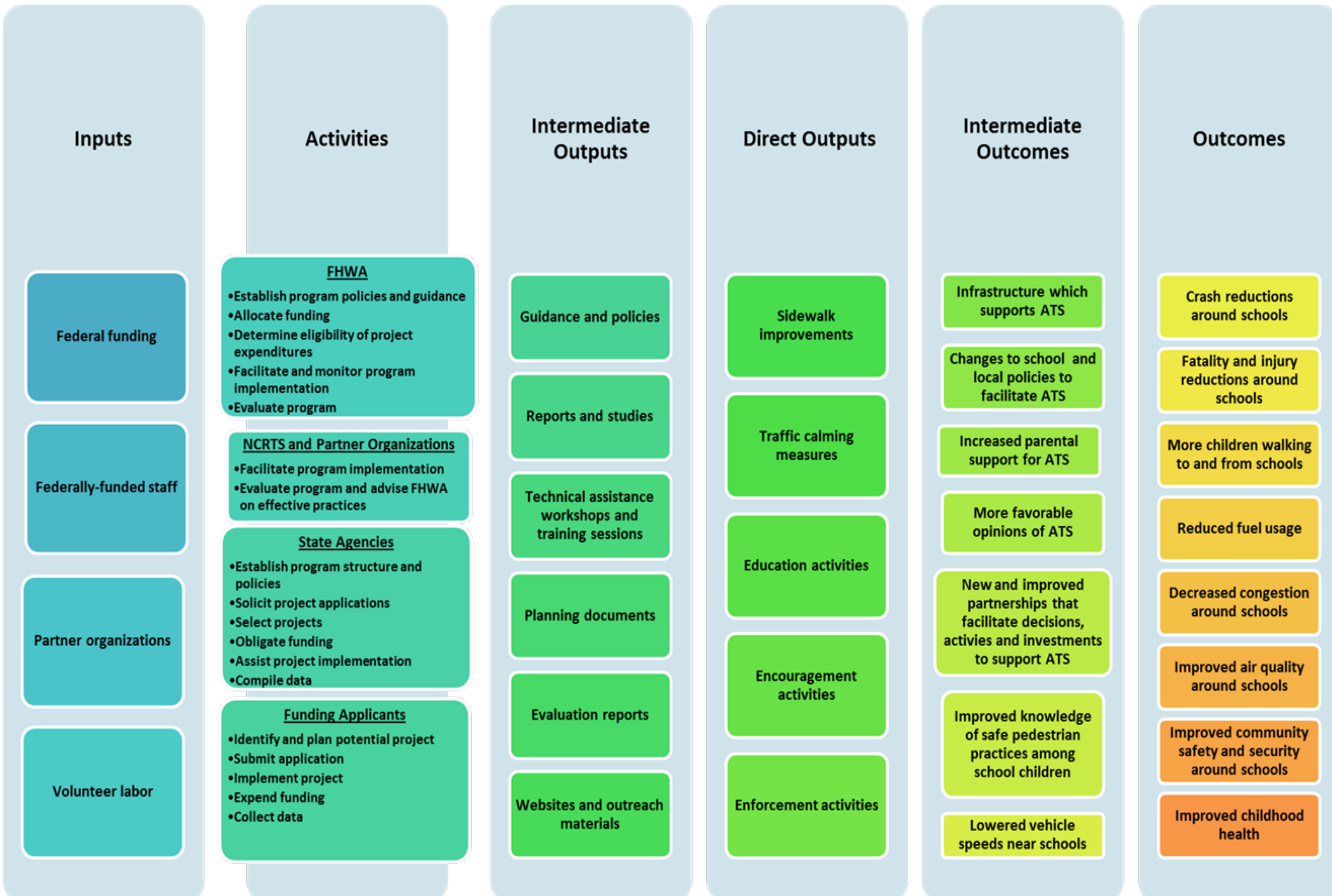


**Figure 5-2. A Sample U.S. Logic Model (*Source: U.S. DOT, Safe Routes to School Program, 2013*)**

### 5.1.2 Japan's Approach

In Japan, a phased evaluation approach, shown below in Figure 5-3, adapted from the systems engineering "V" model, is used in the research and development of safety-related systems.

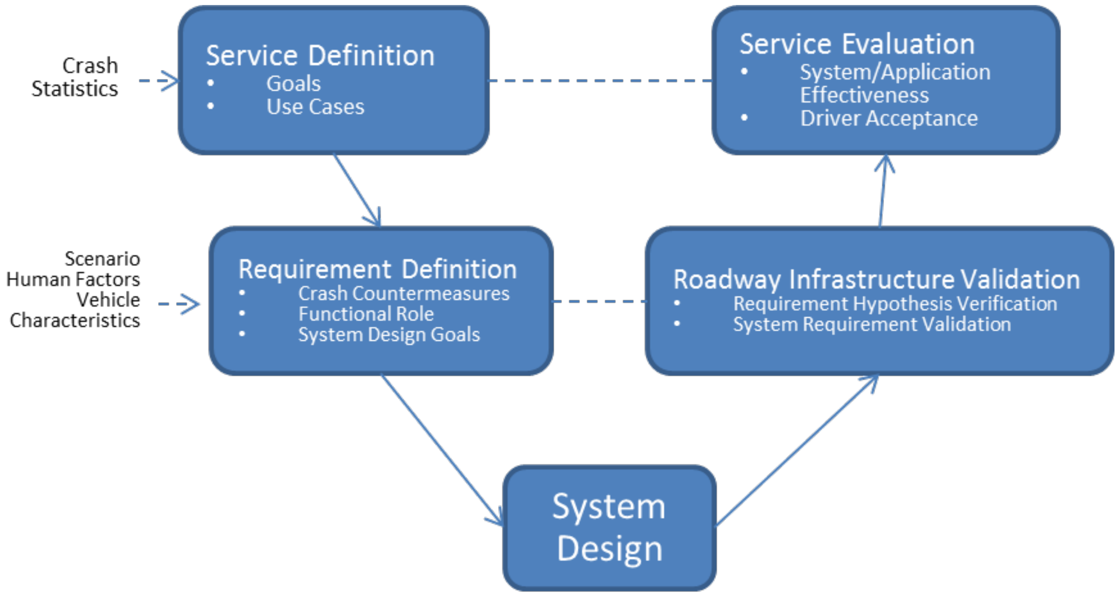


**Figure 5-3: Overview of MLIT's approach to evaluating cooperative systems (*Source: MLIT*)**

First, crash data are used to refine the service goals and use cases in the service definition. Next, requirements, including crash countermeasures, functional roles, and goals, are defined, with the usage scenario, human factors, and vehicle characteristics as inputs. There are two phases of evaluation: first, the roadside infrastructure systems are validated. This stage of evaluation includes technical feasibility and system reliability. Next, the effectiveness of the service, including user benefits, is evaluated.

Three main methods are used to measure data and effectiveness when validating infrastructure systems. First, in the early stages of development, driving simulators are used for observation of driver behavior and basic system characteristics in a safe, controlled environment. Next, test drivers on a test track are used to evaluate performance in near real-world conditions, while controlling surrounding traffic and other factors. Finally, field operational tests are performed. These allow evaluation of not only the equipped vehicle but also of the surrounding non-equipped vehicles.

## 5.2 Summary of Evaluation Tools and Methods Used in the U.S. and Japan

### 5.2.1 Summary of Evaluation Tools and Methods Used in the U.S.

This section summarizes existing evaluation tools and methods used in the U.S. to assess performance and benefits of ITS and connected vehicle systems.

#### *5.2.1.1 Urban Partnership Agreement (UPA) and Congestion Reduction Demonstration (CRD)*

The goal of the National Urban Partnership Agreement Program is to reduce congestion through the use of ITS technologies. In 2008, six sites (Atlanta, Miami, Minnesota, Los Angeles, Seattle, and San Francisco) were selected by the U.S. DOT to demonstrate congestion reduction strategies. The evaluation efforts were sponsored by the ITS Joint Program Office, Federal Highway Administration, and Federal Transit Administration. Each evaluation project specifically addressed four key questions:

1. What was the reduction in congestion due to the implementation of the CRD projects?
2. What are the associated impacts of implementing the congestion reduction strategies?
3. What are the lessons learned with respect to the impacts of outreach, political and community support, and institutional arrangements implemented to manage and guide the implementation?
4. What are the benefits and costs of the congestion reduction strategies?

These demonstrations are being evaluated following the approach detailed in the National Evaluation Framework [1].

##### 5.2.1.1.1 National Evaluation Framework

The national evaluation framework recommends a “before and after” analysis study as the approach for quantifying the extent to which the strategies affect congestion in the UPA/CRD sites. The “before” or baseline period is the period prior to deployment of congestion reduction strategies, and the “after” or the post-deployment period is the period after the strategies are deployed. Data are collected for at least one year during the baseline period, and one year during the post-deployment period to calculate performance measures (see discussion below).

The analysis approach tracks how the performance measures change over time (trend analysis) and examines the degree to which they change between the “before” and “after” periods, as a result of the congestion reduction strategies. Whenever possible, field-measured data are used to generate the performance measures. The national evaluation data collected includes both objective data from available sources such as traffic counts, travel times, transit ridership, and costs, as well as subjective data such as traveler and stakeholder perceptions gathered through surveys, focus groups, and interviews.

The analysis approach also features consideration of external effects that may have an impact on the evaluation of the UPA/CRD projects. External effects may manifest in various ways, including changes to fuel prices, the status of the local economy and employment, and also the impact of transportation improvements that are outside the scope of the particular UPA/CRD project.

**Congestion Reduction**: Congestion reduction evaluation examines if the congestion reduction strategies are able to reduce the impact of congestion in an urban corridor or area and improve mobility. The performance measures that are estimated or calculated include: travel time, travel time reliability, spatial and temporal extent of congestion and throughput (vehicle and person). In addition to these quantitative mobility measures, traveler perception of congestion is also measured through surveys. (A freeway segment is congested when the average speed on the segment is less than 50 mph and severely congested when the average speed is less than 30 mph. An arterial segment is congested when the average speed drops 10 mph below the posted speed limit, and severely congested when the speed drops 15 mph below the posted speed limit.)

**Tolling**: Tolling evaluation examines if vehicle throughput and parking utilization can be improved by tolling roadways and adopting variable parking pricing. Key measures that are calculated or estimated include: Travel time reliability, throughput, average vehicle occupancy, and turnover rate for parking based on pricing rate for time of day on tolled lanes versus general purpose lanes.

**Transit**: Transit evaluation examines if transit-related strategies are able to increase transit's utility relative to the private auto, leading to a mode shift to transit thereby reducing congestion, and increasing efficient use of existing road capacity, person throughput, and transit ridership. Key measures include: end-to-end travel time, service reliability, park-and-ride utilization, transit ridership, and transit riders' perception of service reliability.

**Telecommuting**: Telecommuting evaluation examines if travel demand management (TDM) measures, such as telecommuting programs, vanpooling, carpool promotion, and walking and bicycling initiatives, are able to improve traveler choices trip-making choices and mode shift. Key measures include: vehicle miles traveled, mode shift, travel shift to off-peak hours, teleworkers' and employers' perceptions about telecommuting experience, travelers' trip behavior changes with respect to ridesharing and eliminating/rescheduling of trips.

**Technology**: Technology evaluation examines if the technologies that are deployed are able to support the objectives of the congestion reduction strategies. The intent is to isolate the extent to which the technologies contributed to congestion reduction in the corridor where they are deployed. Key measures include: percent change in travel time reliability, percent change in throughput, percent change in route/corridor travel time, percent change in incident duration, frequency and time to normal flow, percent change in number of hours of congested flow.

**Safety**: Safety evaluation examines if congestion reduction strategies are able to prevent primary and secondary crashes. The evaluation will examine if the strategies result in degradation of safety.

**Environment**: Environmental evaluation examines if the impact of congestion reduction and efficiency improvements do not have a negative impact on the environment. The environmental analysis will address three elements: air quality, noise, and energy, and will specifically examine if the changes are due to the UPA/CRD strategies and not exogenous factors. Air pollutants that will be analyzed include: ozone precursors (hydrocarbons, reactive organic gases, and volatile organic compounds, or HC, ROG, and VOC), NOx, PM2.5, and CO2. If noise monitoring data are available, noise impacts will be modeled using the FHWA Traffic Noise Model [3]. Energy impacts will be calculated by assessing fuel consumption and fuel efficiency.

**Cost-Benefit Analysis**: The purpose of the cost and benefit analysis (CBA) is to quantify and monetize the potential costs and benefits that may be incurred as a result of implementing the project. The time frame that the CBA will cover includes: (1) the first year after implementing the UPA/CRD project and (2) an estimate for a 10-year period after implementing the UPA/CRD project. Within this evaluation time frame, the CBA will compare and analyze traffic conditions under two scenarios—before and after implementing the UPA/CRD project.

Each UPA/CRD site has customized the evaluation framework to develop site-specific plans (including hypotheses and performance measures) and conduct site-specific evaluations. These are discussed below.

#### 5.2.1.1.2 UPA/CRD - Minnesota

**Evaluation Goal**

The goal of the evaluation was to assess if the Minnesota CRD projects were successful in reducing traffic congestion in the Interstate-35 West (I-35W) corridor and in downtown Minneapolis. Specific projects that were evaluated include [4-13]:

- High occupancy toll (HOT) lanes and a priced dynamic shoulder lane (PDSL) on I-35W South;
- Transit improvements including, 27 new buses, double contraflow bus lanes on Marquette and 2nd Avenues (MARQ2) in downtown Minneapolis, a “Transit Advantage” bus bypass lane/ramp at the Highway 77/Highway 62 intersection, and six new or expanded park-and-ride facilities;
- Technology improvements including, Drive Assist System (DAS) for shoulder-running buses; real-time transit and next bus arrival information; Active Traffic Management signs for speed harmonization; and
- Telework program (eWorkPlace).

Figure 5-4 shows the Minnesota UPA-CRD deployment area.

**Hypotheses**

The following are congestion-related hypotheses:

- Deployment of the UPA improvements will reduce the travel time of users in the I-35W corridor.
- Deployments of the UPA improvements will improve the reliability of user trips in the I-35W corridor.
- Traffic congestion on I-35W will be reduced to the extent that travelers in the corridor with experience a noticeable improvement in travel time.
- Deployment of the UPA projects will result in more vehicles and persons served in the I-35W corridor during peak periods.
- A majority of survey respondents will indicate a noticeable reduction in travel times after the deployment of the UPA improvements.
- A majority of survey respondents will indicate a noticeable improvement in trip-time reliability after the deployment of the UPA projects.
- The majority of survey respondents will indicate a noticeable reduction in the duration of congestion after the deployment of the UPA projects.
- A majority of survey respondents will indicate a noticeable reduction in the extent of congestion after the deployment of the UPA projects.

The evaluation report also includes hypotheses developed for tolling, transit, telecommuting, technology, safety, equity, and environmental impacts [4].

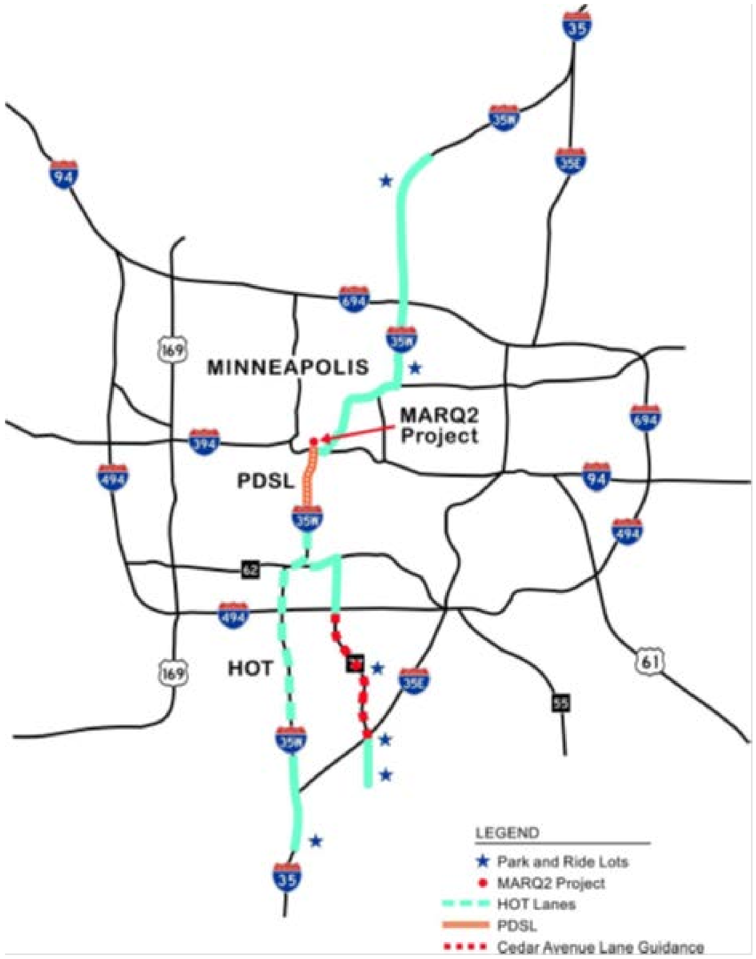


**Figure 5-4: Minnesota UPA Deployment Area (*Source: Battelle, 2013, [3]*)**

**Performance Measures**

- Transit
  - Travel time savings
  - Bus on-time performance
  - Bus operating speed
  - Bus throughput
  - Park-and-ride lot daily usage
  - Total annual regional transit ridership
- Telecommuting
  - Average number of telework days
  - Daily average number of peak-hour trips
  - Mode choice on non-telework days
  - Average daily VMT per person saved on telework day (vs. office day)
- Congestion
  - Mean corridor peak-period travel times
  - $95^{th}$ percentile travel time

    - Buffer Index
    - Mean peak-period travel speeds
    - Median peak-period per-lane vehicle throughput
    - Mean peak-period flow rates (vehicles per hour per lane)
    - Median Peak-Period Vehicle Miles Traveled (VMT)
- Tolling
    - Frequency of Use
    - Total Daily trips
    - Total Monthly trips
    - Total Daily Revenue
    - Total Monthly Revenue
    - HOT Violations
- Technology
    - Traveler comprehension of signage
- Traveler satisfaction

**Evaluation Approach**

The evaluation report includes detailed evaluation approaches used for testing each hypothesis [4]. Following the national evaluation framework, a before (pre-deployment) and after (post-deployment) data collection approach was used to evaluate the impacts of the CRD projects on commuters and other stakeholders, operations, and the environment. A detailed description of the analysis techniques are provided in in the Final Evaluation Report [4].

The evaluation report included a cost-benefit analysis for the UPA projects. The analysis includes all costs beginning with the first project cost incurred, and includes the 10-year period after implementation. For projects with useful lives longer than 10 years, the cost subtracted the “salvage value” of the project/equipment in year 10. Finally, future costs (and benefits) were discounted at a rate of 7 percent.

Costs were obtained from MnDOT and Metro Transit, and included capital costs, implementation costs, operation and maintenance costs, replacement and reinvestment costs, and program costs (e.g., for the Minnesota eWorkPlace program). The total 10-year discounted costs were estimated to be $83.3 million. Benefits that were monetized and incorporated into this analysis include travel-time savings, safety benefits, fuel savings, and emissions reductions. Each of these benefits were quantified and monetized as follows:

- **Travel-time savings** for automobile travelers were quantified as the total time saved (in vehicle-hours) by all travelers over the course of the study period. This hourly value was then multiplied by the local value of traveler time, based on FHWA guidance [14]. In 2009, the value of traveler time in the region was $12.50. This same methodology was used for transit passengers. The total monetized travel-time savings were $139.5 million for automobile travelers and $45.3 million for transit riders.
- **Safety benefits** quantified the reduction in vehicle crashes, and multiplied this value by the weighted cost of a possible/definite injury/fatality crash. The weighted values of each crash scenario were calculated using the DOT Value of a Statistical Life (VSL) [15], and taken proportionally based on the crash severity. The analysis therefore multiplied the number of crashes falling in each injury category (ranging from “no injury” to “killed”) by

the respective cost of that crash, in terms of property and injury loss of life. The total monetized safety benefits were $317.6 million.

- **Fuel savings** were quantified as gallons saved per year from reduced congestion. The number of gallons saved was then multiplied by the price of one gallon of gas. For 2010 and 2011, the analysis used U.S. Energy Information Administration (EIA) data on fuel prices [16]; the price of fuel for future years was based on the data from the Final Regulatory Impact Analysis for Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks [17]. The total monetary benefit of fuel savings was $2.9 million.
- **Emissions benefits** were quantified using the reduction in fuel consumption (in gallons), as presented as total tons per year of CO, CO2, NOx, and VOC. To monetize the value of emissions, the analysis multiplied the tons per year by the U.S. EPA estimate of the value of health and welfare-related damages for each emission. The total monetary benefits of emissions reduction was $399,000.

Thus, the total benefit was $505.6 million and the net benefit, which is calculated by subtracting the cost from the benefit, was $422.3 million. The benefit-cost ratio was 6.1.

**Data**

The types of data collected as part of this evaluation effort were numerous because of the large number of performance measures calculated. Data types included sensor data, traveler surveys (multiple), interviews and workshops, incident data, manual counts, transit vehicle polling data, and electronic tolling transponder data. There may have been some personally- identifiable information (PII) that would be included in the electronic tolling transponder data. The data sources, data availability, methods of data collection and analysis, and project risks are outlined in the Test Plans. The evaluation period differed slightly depending on the performance metric being evaluated:

- Pre-deployment sensor data were gathered between October 2008 and April 2009.
- Post-deployment sensor data were gathered between December 2010 and November 2011.

**Key Findings/Outcomes**

A key outcome is that the UPA projects provide the capacity for further growth in the corridor and provide ongoing travel options for residents and visitors.

Of the hypotheses listed in the Hypotheses section above, the only hypothesis that was not supported by the data was “Deployment of the UPA projects will not cause an increase in traffic congestion on surrounding facilities adjacent to I-35W.” This hypothesis was ultimately untested because of a lack of data on the surrounding roadway facilities. The hypothesis of reduced travel times was only somewhat supported because travel time savings varied by section. Other findings include:

- I-35W HOT Lanes and PDSL:
    - Total monthly revenues increased from $19,609 in October 2009 to $94,619 in November 2011.
    - Vehicle volumes in the HOT lanes increased due to MnPASS users.
    - The number of vehicles violating the occupancy requirements declined.
- Transit:
    - Use of the park-and-ride lots increased.

  - Bus ridership on routes serving the I-35W South and Cedar Avenue park-and-ride lots increased by 13 percent.
  - The MARQ2 lanes in downtown Minneapolis have resulted in increased bus operating speeds.
  - The HOT lanes have also resulted in increased operating speeds and reduced travel times, although a slight decline in speeds was noted in one section.
- Telecommuting:
  - Participant survey data revealed that the Telework Program eliminated over 1,260 solo car trips per week, for an annual reduction of 0.52 million vehicle miles traveled (VMT) in the I-35W South corridor.
- Technology:
  - Technologies were successfully deployed and have enhanced operation of I-35W South and provided improved information for bus riders and motorists.
  - No negative impacts on safety from these projects were identified.
- Equity:
  - All user groups, geographic areas, and socio-economic groups were found to benefit from the UPA projects.
- Environmental:
  - Vehicle emissions reduced in the section south of I-494, with inconclusive results in other sections.
- Non-Technical Success Factors:
  - Local partners built on existing strong working relationships and established new collaborative approaches. There was clear authority and responsibility for project deployment. The local print media was objective and generally supportive of the UPA projects.
- Benefit-Cost Ratio:
  - The UPA projects on I-35W South corridor, the MARQ2 lanes in downtown Minneapolis, the portion of the telecommuting program focusing on the I-35W South corridor, and the reconstruction of the Crosstown Common section had a benefit-cost ratio of 6.1.

**Challenges and Issues**

- *Exogenous Factors:* Several issues were identified that might have impacted the evaluation. During the initial implementation of the UPA projects, Minnesota, and Minneapolis-St. Paul experienced high unemployment rates. These might likely have impacted the effectiveness of the UPA projects. Secondly, gasoline prices increased from the pre-deployment to post-deployment periods. These increases in gasoline prices might have also influenced travel behavior.
- *Quantifying and Monetizing Benefits:* In the analysis, the Evaluation Report acknowledged that it is difficult to attribute costs and benefits to one project only. This is a result of multiple improvement projects—with overlapping benefits—occurring simultaneously in a close area. For example, the general purpose freeway lanes in the Crosstown Commons section were not part of the UPA, but potentially contributed to the benefits seen in the UPA study. Finally, other projects were under construction on I-35W South at the same time as the UPA projects. This situation made evaluation of the UPA projects more difficult as the pre-deployment period was impacted by construction and the post-deployment period was influenced by the operation of these projects as well as the UPA projects. Further, the multiple projects made it

more difficult to separate and brand the UPA projects, causing some confusion on the part of policy makers and the public.

#### 5.2.1.1.3 UPA/CRD - Atlanta

**Evaluation Goal**

The goal of the evaluation was to assess if the Atlanta CRD projects were successful in reducing traffic congestion along the I-85 corridor. Specific projects that were evaluated include [18-29]:

- Conversion of existing 2+ person high occupancy vehicle (HOV) lanes to dynamically-priced 3+ person high-occupancy toll (HOT) lanes, called Express Lanes, on approximately 16 miles of I-85 northeast of Atlanta;
- Transit enhancements, where 36 new buses enabled operation of five new routes on the corridor, and park-and-ride lot enhancements;
- Automated enforcement systems that utilize radio frequency identification (RFID) readers, a license plate recognition system, and mobile automatic license plate readers (ALPR) camera systems; and
- Carpooling outreach to increase the number of 3-person carpools.

Figure 5-5 shows the Atlanta UPA/CRD deployment area.

**Hypotheses**

The following are congestion-related hypotheses:

- Converting the I-85 HOV lanes to HOT operations will improve travel time and average travel speeds on both the general purpose and high occupancy lanes on I-85.
- Converting the I-85 HOV lanes to HOT operations will improve travel time reliability and reduce variability on both the general purpose and high occupancy lanes on I-85.
- Deploying the CRD improvements will result in more vehicles and persons being served on I-85.
- Implementing the CRD improvements in the I-85 corridor will reduce the spatial and temporal extent of congestion
- As a result of the CRD improvements, the perception of travelers is that congestion has been reduced in the I-85 corridor

The evaluation plans also include hypotheses developed for pricing, telecommuting/TDM, technology, equity, environmental impacts, etc. [18-29].

**Performance Measures**

The following are a few key measures that were used to test the hypotheses in the Test Plans:

- Travel time and travel speeds
- Travel time reliability (buffer index, planning index)
- Throughput (vehicle, person)
- Users' perceptions of congestion on I-85
- Emission factors for criteria and greenhouse gases (GHG)

- Fuel consumption factors
- Incident type and location, Incident severity
- Violations
- Mode Shift, Ride matching registrants, New vanpools and vanpoolers, Employer and employee participation
- Toll use, revenue
- Transit travel times and speed
- Transit ridership, Service reliability, Service quantity, Travel time
- Park-and-Ride lot capacity and utilization
- Benefit to Cost Ratios (Value of travel time savings, Operating cost Savings, Improved Air Quality, O&M Cost Savings, Salvage Cost Savings, Cost of transit buses, Cost of Park-and-Ride lots)

Additional measures are available in the evaluation report [29].

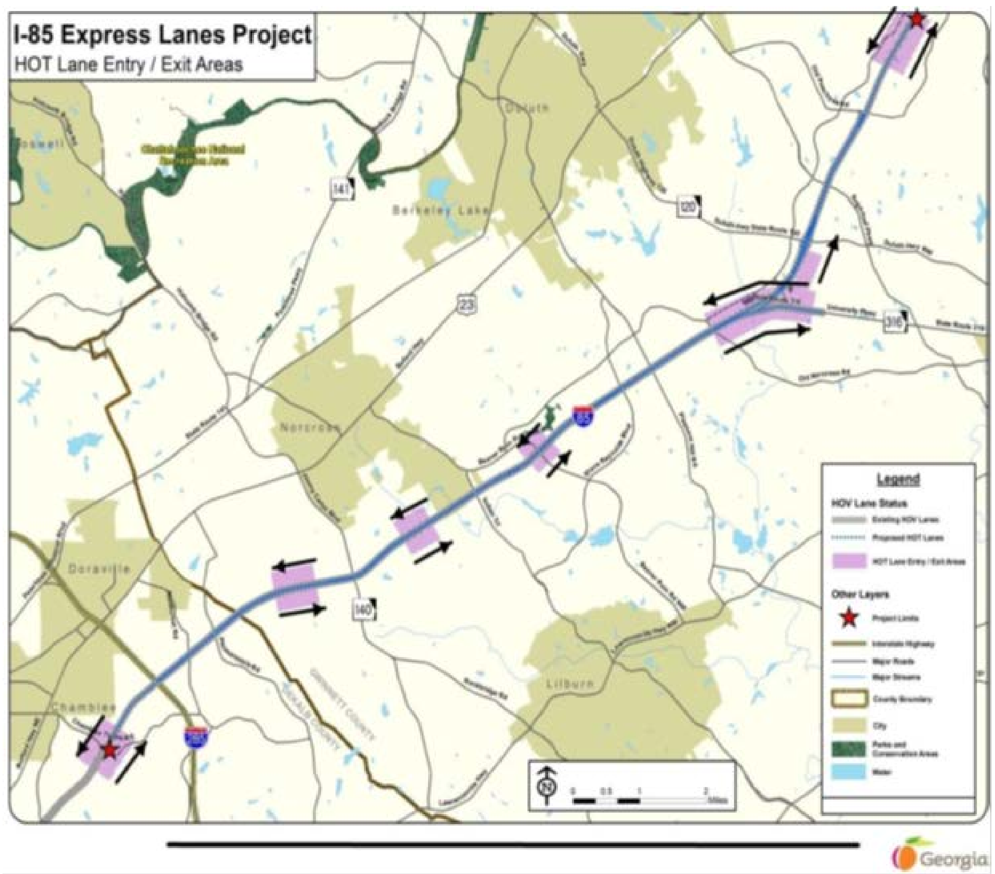


**Figure 5-5: Atlanta I-85 HOV to HOT Conversion Project (*Source: Battelle, 2013, [29]*)**

**Evaluation Approach**

The evaluation report includes detailed evaluation approaches used for testing each hypothesis [29]. A before (pre-deployment) and after (post-deployment) data collection approach was used to evaluate the impacts of the CRD projects on commuters and other stakeholders, operations, and the environment. A detailed description of the analysis techniques are provided in the evaluation report [29].

The evaluation report included a cost-benefit analysis for the UPA projects. The analysis includes all costs beginning with the first project cost incurred, and includes the 10-year period after implementation. For projects with useful lives longer than 10 years, the cost subtracted the "salvage value" of the project/equipment in year 10. Finally, future costs (and benefits) were discounted at a rate of 7 percent.

Costs were obtained from the Georgia State Road and Tollway Authority (SRTA), Georgia Department of Transportation (GDOT), and Georgia Regional Transportation Authority (GRTA), and included marginal capital costs, implementation costs, operation and maintenance costs, replacement and reinvestment costs, and program costs. The total 10-year discounted costs were estimated to be $77.9 million. Benefits that were monetized and incorporated into this analysis include travel-time savings, safety benefits, fuel savings, and emissions reductions. Each of these benefits were quantified and monetized as follows:

- **Travel-time savings** for automobile travelers were quantified as the total time saved (in vehicle-hours) by all travelers over the course of the study period. This hourly value was then multiplied by the local value of traveler time, based on FHWA guidance [14]. In 2009, the hourly value of traveler time to the region was $12.50. This same methodology and value of $12.50 per hour was used for transit passengers.
- **Safety benefits** quantified the reduction in vehicle crashes, and multiplied this value by the weighted cost of a possible/definite injury/fatality crash. The weighted values of each crash scenario were calculated using the DOT Value of a Statistical Life (VSL) [15] and taken proportionally based on the crash severity. The analysis therefore multiplied the number of crashes falling in each injury category (ranging from "no injury" to "killed") by the respective cost of that crash, in terms of property and injury loss of life.
- **Fuel savings** were quantified as gallons saved per year from reduced congestion. The number of gallons saved was then multiplied by the price of one gallon of gas. For 2010 and 2011, the analysis used U.S. Energy Information Administration (EIA) data on fuel prices [30]; the price of fuel for future years was based on the data from the Final Regulatory Impact Analysis for Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks [17].
- **Emissions benefits** were quantified using the reduction in fuel consumption (in gallons), as presented as total tons per year for CO, CO2, NOx, and VOC. To monetize the value of emissions, the analysis multiplied the tons per year by the U.S. EPA estimate of the value of health and welfare-related damages for each emission.

**Data**

The data sources, data availability, methods of data collection and analysis, and project risks are outlined in the evaluation report:

- Before CRD deployment data were collected from September 2009 to approximately September 2010
- After CRD deployment data were collected from approximately October 2011 to September 2012

**Key Findings**

The following findings were presented in the Final Evaluation Report [29]:

- Congestion Analysis:
  - During the peak periods travel times and speeds improved slightly in the Express Lanes but grew worse in the general purpose lanes, resulting in a substantial travel time advantage of 3 minutes or more for Express Lane users.
  - Travel reliability in the Express Lanes improved in the PM peak but not in the AM peak.
  - Vehicle throughput declined as did VMT in the corridor. Even with an increase in transit, peak period person throughput declined in the AM and the PM.
  - Average occupancy levels declined in the Express Lanes as 2-person carpools shifted to the general purpose lanes.
  - Results of surveys and focus groups showed a perception that congestion had not improved in the corridor.
- Tolling Analysis:
  - Monthly Express Lane usage reached approximately 400,000 from March through September 2012, with tolled trips accounting for about 300,000 and HOV 3+ trips for about 29,300 per month.
  - Variable pricing was more effective in regulating Express Lane traffic flow in the AM peak than in the PM peak.
  - A total of 388,296 transponders were in service by September 2012, but their usage was fairly intermittent, the median being two trips per month. In all, 4.6 percent of tolled users and 3.2 percent of HOV 3+ users took 20 or more trips in the Express Lanes.
- Transit Analysis:
  - Peak period Express bus ridership increased by 21 percent in the AM and by 17 percent in the PM, although much of the increase occurred as CRD transit enhancements came on-line prior to tolling.
  - Usage of CRD-funded routes and park-and-ride lots increased as non-CRD funded transit in the corridor declined.
  - About half of new riders said tolling influenced them to start taking the bus. Express riders expressed very high satisfaction with the bus service, although post-tolling surveys suggested that some riders perceived slower bus travel time despite actual travel time being better or unchanged.
- TDM Analysis:
  - Targeted outreach to carpoolers resulted in only 18 carpools adding a third person to be able to use the Express Lanes for free.
  - Carpools of all sizes declined in both the Express Lanes and general purpose lanes.
  - A substantial shift from the Express Lanes to the general purpose lanes by 2-person carpools can be attributed to the change to HOV lane use requirement from HOV 2+ to HOV 3+.
- Technology:
  - Violations detected by the gantry-controlled access system resulted in 50,636 citations being issued by State Roadway and Tollway Authority (SRTA).
  - SRTA operators expressed satisfaction with system features for optimizing violation detection.

  - Department of Public Safety (DPS) personnel using the automatic license plate reader in their vehicles issued an average of 47 occupancy citations per month. DPS also issued an average of 21 citations to drivers crossing the double white line.
- Safety:
  - Crashes increased on the I-85 corridor within Gwinnett and DeKalb counties, although isolating those just on the CRD portion of the corridor was not possible with the data. The number of crashes, including sideswipe and angle crashes, increased in the post-deployment period.
  - Citation data indicate that the number of monthly manual citations for crossing the double white line varied but did not decline significantly over time.
- Equity:
  - Transit riders were found to benefit the most in terms of lowest cost and faster travel on I-85.
  - There was a perception of unfairness on people with limited income due to tolling on I-85.
- Environmental:
  - Generally positive impacts on five air quality measures were identified, with all but one pollutant showing a net decrease.
  - Fuel consumption declined slightly.
  - Express Lanes outperformed the general purpose lanes, but the total impact was still positive.
- Non-Technical Success Factors:
  - Staff worked well together and helped the local partners in implementation, deployment, and operations of the CRD projects.
  - An ambitious communications and outreach plan was developed, but media coverage leaned towards the negative during the opening of the Express Lanes and missed telling the public about the transit enhancements. Post-deployment surveys showed that I-85 travelers tended to have a negative view of the Express Lanes.

**Challenges and Issues**

Several issues were identified that might have impacted the evaluation.

- *Exogenous Factors:* During the initial implementation of the UPA projects, Atlanta experienced high unemployment rates. These might likely have impacted the effectiveness of the UPA projects. Secondly, gasoline prices fluctuated throughout the evaluation period. In the pre-deployment period one year before the Express Lanes opened in October 2011, the price increased from $2.70 the week of September 27, 2010 to a peak of $3.97 in May 2011 to $3.51 the week of September 26, 2011. For the post-deployment period, the price fluctuated between $3.26 and $4.00. These changes in gasoline prices may have influenced travel behavior. Finally, the post-deployment period was affected by unanticipated operational and physical changes to the Express Lanes. After the opening of the Express Lanes, low volume in the tolled lanes and congestion and slow speeds in the general purpose lanes generated a negative environment of public opinion such that decision makers felt compelled to respond. Consequently, to increase demand, the peak-period tolling algorithm was altered and rates for off-peak hours were set to a minimum of $0.01 per mile.
- *Quantifying and Monetizing Benefits:* One challenge identified in the report is the difficulty in distinguishing the cause of traffic accidents. The proposed hypothesis was that the CRD project would have no impact on crashes. However, the analysis found there to be an

increase in crashes in the post-deployment period, though the analysis was unable to attribute the root cause of these accidents to the new CRD project. Therefore, if the accidents were to occur regardless of the CRD project, the safety disbenefits (and total net benefits) identified in this study are significantly overstated (understated).

#### 5.2.1.1.4 UPA/CRD - Miami

**Evaluation Goal**

The goal of the evaluation is to assess if the Miami CRD project was successful in reducing traffic congestion along the Interstate-95 (I-95) corridor between Interstate-595 (I-595) in Broward County and I-395 in Miami-Dade County. The project involved replacing HOV lanes on a segment of I-95 with '95 Express Lanes' based on a HOT lane concept and augmenting it with enhanced transit and travel demand management services [31].

Figure 5-6 shows the Miami UPA/CRD deployment area.

**Hypotheses**

The Miami-CRD evaluation project examined the following hypotheses/questions:

- The UPA project will enhance transit performance (through reduced travel times, increased reliability, increased capacity, etc.
- The UPA project will increase ridership and facilitate a mode shift to transit.
- Mode shift to transit/increased ridership will contribute to congestion mitigation.
- What was the contribution of each UPA project element to increased ridership and/or mode shift to transit?

**Performance Measures**

The following are a few key measures that were used to test the hypotheses:

- Mobility
  - Transit Travel Time, Delay, Run time reliability, On-time performance
  - Ridership changes
  - Mode access and usage history
  - HOT lanes and General Purpose (GP) lane usage
- Throughput
  - Vehicle capacity
  - Transit service capacity
  - HOT lanes and GP lanes usage
- Safety
  - Transit incidents/accidents
  - Perceptions of safety
- Productivity
  - Capital and operating costs
  - Effectiveness/efficiency
  - Park-and-Ride lot usage

    - Ridership changes
- Customer Satisfaction
    - Awareness, User perceptions
    - Demographics
    - ADA Compliance

Additional measures are available in the report.


Managed Lanes Network Map

**Figure 5-6: Miami Managed Multi-Lane Network Project Map (*Source: U.S. DOT, Miami Congestion Reduction Demonstration, 2013, [*31*]*)**

**Evaluation Approach**

Phase 1 included a three year longitudinal study. Before and after data were collected incrementally as the system was built and implemented. The study identified three principle areas, each having at least two performance measures. To quantify enhanced transit performance, the study calculated on-time performance, scheduled travel times, actual travel times, travel speeds, and park and ride lot utilization. To measure increased ridership and transit mode shifts, the analysis calculated average weekday ridership, boarders per revenue mile, average vehicle occupancy, and transit mode share. Finally, congestion mitigation used performance metrics to include person throughput and roadway Level of Service (LOS).

The results of these performance metrics are detailed in the Final Evaluation Report. Enhanced transit performance metrics are quantified in terms of on-time performance (percent); time savings (e.g., reduced travel time in minutes); average travel speeds; and utilization of parking facilities. Ridership metrics use ridership (percent); boardings per revenue-mile; and transit mode share (percent), among others. Finally, congestion mitigation has been quantified in terms of person throughput and roadway LOS.

Although the study quantified the impacts of the Miami CRD project, the analysis did not identify the monetary impacts. However, with the available information, it is feasible to calculate, in the least, simple cost and/or benefit metrics. Examples of benefit metrics that could be incorporated into this analysis include productivity increases (using travel time savings), fuel savings (using gasoline prices), and others. Similarly, additional costs include the costs of infrastructure to accommodate changes in ridership and additional fees and tolls paid by transit and express lane travelers, etc.

**Data**

Field data collected to evaluate Phase 1 performance measures

- January to April 2008 - Baseline period
- January to April 2009 - Phase 1A post-deployment period (northbound lanes)
- January to April 2010 - Phase 1B post deployment period (southbound lanes)

Transit mode share and transit travel time impacts were considered using data from FDOT's I-95 Lane Monitoring Reports. These data were compared against the outputs of similar studies conducted in prior years as documented in FDOT's biannual HOV Lane Monitoring Reports.

Pre and post deployment on-board surveys were conducted to assess the impact of Miami UPA Phase 1 on transit user perceptions.

**Key Findings**

Key findings with respect to the four hypotheses are as follows:

- Transit Performance:
  - 95 Express Bus Service has benefitted from the HOV to HOT conversion in improved travel times and on-time performance.
- Transit Ridership:
  - Average weekday ridership on the 95 Express Bus Service increased 57% between 2008 and 2010.
  - Average vehicle occupancy (AVO) and transit mode share in the 95 Express Lanes decreased despite increased transit ridership. These decreases are due to the influx of toll paying single occupant vehicles on the express lanes.
- Congestion Mitigation:
  - Congestion reduced on the I-95 corridor.
  - Between 2008 and 2010, level of service (LOS) improved on both the express lanes and the general purpose lanes.
  - Person throughput increased by 48% in the AM peak period in the southbound direction and by 13% in the PM peak in the northbound direction.

- On-board transit surveys revealed that the 95 Express Lanes Project influenced riders' decisions to use transit.

**Challenges and Issues**

- *Technical Performance:* A key challenge noted was the deployment of strategies with competing priorities. The conversion of HOV lanes to HOT lanes led to a large increase in the number of individuals, particularly choice riders, utilizing the 95 express bus service due to improved travel times. However, the addition of toll-paying SOVs and a decrease in the number of HOV2 and HOV3 vehicles led to an overall decrease in average vehicle occupancy and transit mode share for those lanes.
- *Quantifying and Monetizing Benefits:* One challenge implicit to the evaluation approach is in identifying the previous mode of travel (and associated costs and times). Without surveys and interviews with transit riders and HOT lane users, the study is unable to distinguish the proportion of travelers who changed their travel habits as a result of the CRD project from those who simply benefit from improved travel times, and therefore cannot identify many of the costs or cost savings associated with each person. For example, a cost-benefit analysis requires that the approach understands each rider's previous mode(s) of travel (and the costs and times associated with those modes) and the rider's new mode(s) of travel (and the costs and times associated with those modes). While the latter has been identified for this study, the former requires additional research and outreach to better understand the costs and travel times that travelers previously incurred.

### 5.2.1.1.5 UPA/CRD - Seattle

**Evaluation Goal**

The goal of the evaluation is to assess if the Seattle CRD projects were successful in reducing traffic congestion on State Route (SR) 520 between Interstate 405 (I-405) and Interstate 5 (I-5), a heavily-traveled east-west commuter route across Lake Washington. Specific projects that were evaluated include [32-38]:

- Variable tolling on all lanes of SR 520 between I-405 and I-5.
- Active Traffic Management (ATM) on SR 520 and Interstate 90 (I-90)—the major freeway alternate route located about three miles south of SR 520—including lane control, dynamic message and advisory speed limit signage to alert drivers to delays and direct travel away from incident-blocked lanes.
- Travel time signs to provide travelers headed toward Seattle with real-time travel time estimates for SR 520 and alternate routes.
- Enhanced bus service on SR 520 adding 90 one-way peak period trips and including purchase of 45 new buses.
- Improvements to transit stops/stations including improvements to two park-and-ride lots, one of them part of a broader transit oriented development (TOD), and real-time information displays at stops/stations.
- Various travel demand management strategies funded locally such as employer-based strategies to promote ridesharing or telecommuting.
- Regional ferry boat improvements which will not be evaluated because they are not expected to impact SR 520 corridor travel.

Figure 5-7 shows the Seattle/Lake Washington UPA deployment area.


**Figure 5-7: Seattle/Lake Washington UPA Deployment Area (*Source: U.S. DOT, Seattle Congestion Reduction Demonstration, 2009, [32]*)**

**Hypotheses**

The following are congestion-related hypotheses:

- Deploying the UPA projects will reduce travel times and increase speeds on SR 520 over Lake Washington.
- Deploying the UPA projects will not increase travel times or decrease speeds on nearby facilities.

The test plans also include hypotheses developed for pricing, telecommuting/TDM, technology, equity, environmental impacts, etc. [32-38].

**Performance Measures**

The following are a few key measures that will be used to test the hypotheses:

- Travel time and travel speed
- Travel time reliability and variability
- Spatial and temporal extent of congestion

- Vehicle and person throughput
- Users' perceptions of congestion on SR 520 and the adjacent alternate routes
- Emissions and fuel consumption
- Collision (frequency, severity, type)
- Incidents (location, duration, type)

Additional measures are available in the report.

**Evaluation Approach**

A before (pre-deployment) and after (post-deployment) data collection approach will be used to evaluate the impacts of the CRD projects. Preliminary approaches are available in the Test Plans. A Final Evaluation Report, which will discuss the evaluation approach and results, is forthcoming.

The approach will include a cost-benefit analysis that calculates travel time savings, savings from changes in vehicle-miles traveled (VMT) and person-miles traveled, and improved travel-time reliability. While travel time savings and VMT and per-miles traveled will be monetized, the analysis will not monetize the savings due to changes in travel-time reliability.

The traffic data collected for the UPA will be used to determine many of the costs and benefits of the plan. Traffic data to be collected will include traffic volume, travel speeds, route travel times, average vehicle occupancy, travel time delay, vehicle throughput, vehicle miles traveled (VMT), and hours of congestion. These data will be used to calculate such metrics as the travel time index (the ratio of average peak travel time to off-peak travel time) and the Buffer Index (the extra time that travelers in a corridor need to allow to ensure an on-time arrival), among others. These traffic data will then be used to measure the impacts of the following:

- **Congestion impacts:** The analysis will calculate congestion impacts in terms of changes in travel time, travel speeds, travel time reliability, and vehicle and person throughput. The analysis does not indicate how these impacts will be monetized, however, other analysis have multiplied, for example, changes in travel times by the value of traveler time to estimate travel time savings ($).
- **Impacts from technology deployment:** The analysis will assess the impacts of improved technology using metrics such as changes in average peak-period traffic volumes, speeds, peak and 95th percentile travel times, and vehicle throughput. Other potential metrics include changes in lane-by-lane variation of peak-period travel, the number of lane-miles operating at or above targeted peak-period speed. The report does not indicate how these impacts would be monetized.
- **Environment impacts:** The analysis will calculate emissions and fuel consumption impacts using (1) emission and fuel consumption facts ("rates") from EPA's MOVES 2010 model, and (2) travel inputs including vehicle-miles traveled (VMT), link speeds, and mode shifts to transit. To quantify the impacts, the analysis will multiply the changes in VMT and speed by these emission rates and fuel consumption factors. The analysis does not indicate how the impacts will be monetized, but other similar analyses have monetized the impacts, for example, by multiplying emissions reductions (in tons) by the EPA value of one ton of that specific pollutant.
- **Safety impacts:** Using crash data from WSDOT Collision Data and Analysis Branch reports, the analysis will incorporate metrics including collision frequency, collision severity, and collision type. The analysis will focus on comparing pre- and post-ICM deployment collision

and incident data, and therefore allow for measuring the effectiveness of measures on safety (as well as other metrics). The analysis will calculate the following: the percent change in crash rates by type and severity, the change in the total number of congestion-causing collisions, the change in the rate of congestion-causing collisions, and the change in the average duration of incident closures. Collisions and incidents will be quantified per 1,000 VMT. The analysis did not indicate how collisions will be monetized. However, monetization approaches used by other studies use the value of a statistical life (VSL) [15] as an input metric.

**Data**

Pre-deployment data was collected during 2009 and 2010. Post-deployment data was collected between 2010 and 2012. Please refer to the Final Evaluation Report for information on the data collected, the data sources, data availability, methods of data collection and analysis, and project risks.

**Key Findings**

Key findings of the Final Evaluation Report include:

- Congestion Reduction
  - Initiation of tolling on SR 520 bridge results in increased peak period travel speed, reduced trips times, and improved travel-time reliability
  - Monthly transactions averaged between 1 and 1.5 million
  - Improved transit performance and increased ridership
  - Slight reduction in VMT
  - Successful deployment of ATM and real-time travel time signage
- Associated Impacts
  - Reduction of number of crashes on SR 520 but increase on I-90 likely due to VMT shift
  - Positive impacts for lower income cohort and transit users, while costs increased for SR 520 and I-90 users
  - 30 percent reduction in fuel usage and emissions on SR 520
- Non-technical Success Factors
  - Strong cooperation between stakeholders
  - Public and acceptance of tolling measures
  - Positive media coverage
- Benefit/Cost Analysis
  - Total deployment BCA of 1.76, attributable to travel time savings and emissions reductions

**Challenges and Issues**

- Findings based on one full year of operations
- Data such as crashes may prove variable over periods longer than one year

### 5.2.1.1.6 UPA/CRD – San Francisco

**Evaluation Goal**

The goal of the evaluation is to assess if the San Francisco UPA/CRD project was successful in reducing congestion in the City of San Francisco. San Francisco UPA projects to be evaluated focus on those related to variable parking pricing. Specific projects that will be evaluated include [39-47]:

- Variable pricing of on-street and off-street parking in the City of San Francisco
- Enhancements to 511 to include parking information
- Integrated payment system for parking and transit
- Expansion of telecommuting/TDM outreach activities

Figure 5-8 shows the San Francisco UPA deployment area.

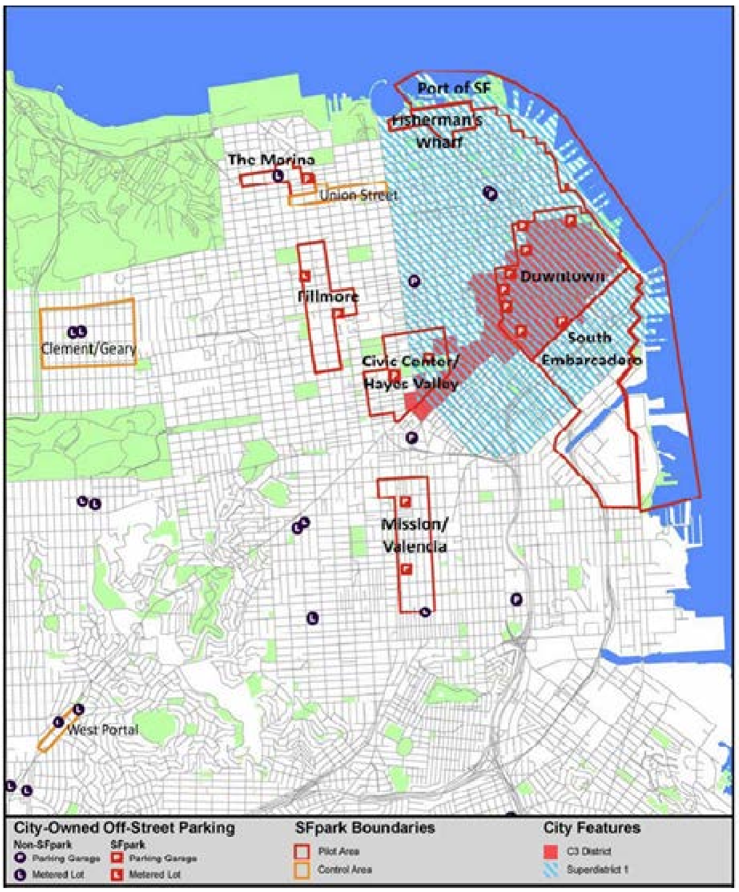


**Figure 5-8: SFpark Pilot and Control Zones (*Source: U.S. DOT, San Francisco Congestion Reduction Demonstration, 2009, [39]*)**

**Hypotheses**

The following are congestion-related hypotheses:

- The deployment of SFpark and the 511 improvements will reduce traffic congestion on selected travel routes in the downtown area
- Travelers will perceive that congestion has been reduced

The evaluation plan also includes hypotheses developed for pricing, telecommuting/TDM, technology, equity, environmental impacts, etc. [39].

**Performance Measures**

The following are a few key measures that will be used to test the hypotheses:

- Travel time and speed
- Travel time index, planning time index, and/or travel time variance on select routes in downtown
- Throughput (vehicle and person)
- Traffic volumes and vehicle occupancy
- Travelers' perceptions of congestion
- Parking availability, parking search time
- Transit schedule adherence, transit travel time and speed, transit ridership
- Mode shift
- Percent error in parking sensor accuracy
- Emissions and fuel consumption

Additional measures are available in the Test Plans.

**Evaluation Approach**

A before (pre-deployment) and after (post-deployment) data collection approach will be used to evaluate the impacts of the CRD projects. Preliminary approaches are available in the Test Plans. A Final Evaluation Report, which will discuss the evaluation approach and results, is forthcoming.

The Evaluation Test Plan proposes to conduct a cost benefit analysis of the San Francisco UPA, including a variable parking pricing system, a regional 511 system, and the promotion of new parking systems. The analysis will calculate the net benefits and the benefit cost ratio, based on a 10-year time period with future costs and benefits discounted at 7 percent. Any projects with useful lives longer than 10 years will include a "salvage value" in the tenth year.

The costs for the analysis will be provided by multiple sources. Cost associated with the project will be provided by the San Francisco County Transportation Agency (SFCTA), San Francisco Metropolitan Transportation Authority (SFMTA), and the Metropolitan Transportation Commission (MTC). Traffic forecasts will be given by the SFCTA's Travel Demand Forecasting Model (SF CHAMP Model). Costs will include: implementation costs, operating and maintenance costs, and replacement and re-investment costs for UPA equipment and infrastructure.

Using the SF Champ Model, the analysis will assess impacts by conducting a pre-UPA and post-UPA run, and identifying the changes in outputs. These impacts will then be converted into monetary terms. Monetization of benefits will be as follows:

- **Travel time savings resulting from improvement in traffic conditions experienced by drivers and transit riders.** The SF Champ Model will determine the travel time savings in hours for both personal vehicle and transit travelers. These hourly values will then be multiplied by the FHWA recommended value of travel time for local travel (including transit passengers and personal vehicle travel), $11.20 in 2000 [14]. Commercial vehicle time savings, also identified through the SF Champ Model, will be multiplied by the FHWA value of truck traveler time, or $18.10 in 2000.

- **Vehicle operating cost savings experienced by drivers as a result of the reduction in congestion.** These costs include both fuel savings and non-fuel (i.e., "wear and tear") costs. The SF Champ model will similarly provide changes in vehicle travel distance and driving speeds, as well as provide the non-fuel costs saved per-mile reduced. To estimate fuel use, the outputs of the SF Champ Model will be incorporated into a model that contains the San Francisco fleet fuel efficiency—for example the Emission Factors (EMFAC) Model. Total fuel savings will then be monetized using projected gasoline prices, taken from the Final Regulatory Impact Analysis for Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks.
- **Improvement in air quality.** Benefits from air quality improvement will be monetized by multiplying the reduction in vehicle miles traveled (VMT) by the dollar cost per ton of emission. The cost per ton of emission is given by the U.S. Environmental Protection Agency (EPA) and can be found in the Final Regulatory Impact Analysis for Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks [17].
- **Improvement in travel time reliability.** Travel time reliability will not be monetized, but will nonetheless be included qualitatively in the analysis. The Test Plan notes that the U.S. does not have a standard method for incorporating travel time reliability estimates into a cost-benefit analysis.
- **Mode shifting data.** Mode shift data includes the number of people changing from driving to riding transit or telecommuting. This is viewed as a benefit, but will not be monetized in the analysis.

**Data**

The Test Plans have outlined the data sources, data availability, methods of data collection and analysis, and project risks. The Final Evaluation Report will discuss the data collected. The baseline data was collected from January 2010 to December 2010 and post-deployment data was collected between April 2010 and spring 2011.

**Key Findings**

Key findings from the Final Evaluation Report include:

- Congestion Reduction
  - Miles traveled cruising for parking reduced by 27 percent on weekdays and 22 percent on Saturdays
  - Consistent negative relationship between demand-based pricing and parking occupancy
  - No effect on transit performance
  - Low awareness and usage of available real-time parking information technology
- Associated Impacts
  - No systematic equity impact
  - Emissions reductions of 27 percent on weekdays and 22 percent on Saturdays
  - No noticeable adverse effects on local business community
  - 21 percent decline in double-parking of commercial vehicles
- Non-technical Success Factors
  - Vigorous program outreach and engagement

  - Highly visible and extensive media coverage
- Benefit/Cost Analysis
  - Net negative BCA of 0.74 projected over ten years due to travel time savings benefits being accrued solely by motorists who directly benefited from reduced time spent searching for parking

**Challenges and Issues**

- Smaller metropolitan areas may not be able to replicate such a data-intensive effort
- Traditional congestion measurements and methods may not be suitable when applied to parking
- Single-agency deployment, mitigating concerns of multi-agency coordination but also perhaps failing to gain useful insights from other organizations
- High percentage of roadway sensors did not provide data of sufficient quality for analysis

### 5.2.1.1.7 UPA/CRD – Los Angeles

**Evaluation Goal**

The goal of the evaluation is to assess if the Los Angeles CRD projects were successful in reducing traffic congestion along the Interstate 19 (I-19) and Interstate (I-110) corridors. Specific projects that will be evaluated include [48-52]:

- Transit improvements including:
  - Reduced headways during peak periods,
  - A new downtown transit operating and maintenance facility,
  - Improved Artesia Transit Center security,
  - Expansion of the El Monte Transit Center,
  - Creation of an El Monte Busway/Union Center connection, and
  - Implementation of additional transit signal prioritization in downtown Los Angeles.
- Conversion of HOV lanes to HOT on I-10 and I-110 freeways,
- Addition an extra HOT lane on I-10 between Interstate 710 (I-710) and Interstate 605 (I-605),
- Intelligent Parking Management (IPM) in downtown L.A. that will make use of demand-based pricing,
- Technology improvements to support HOT and IPM efforts, and
- Ridesharing Expansion (Travel Demand Management) including strategies such as subsidies to travelers and vanpool operators and promotional outreach to major employers.

Figure 5-9 shows the Los Angeles UPA/CRD deployment area.

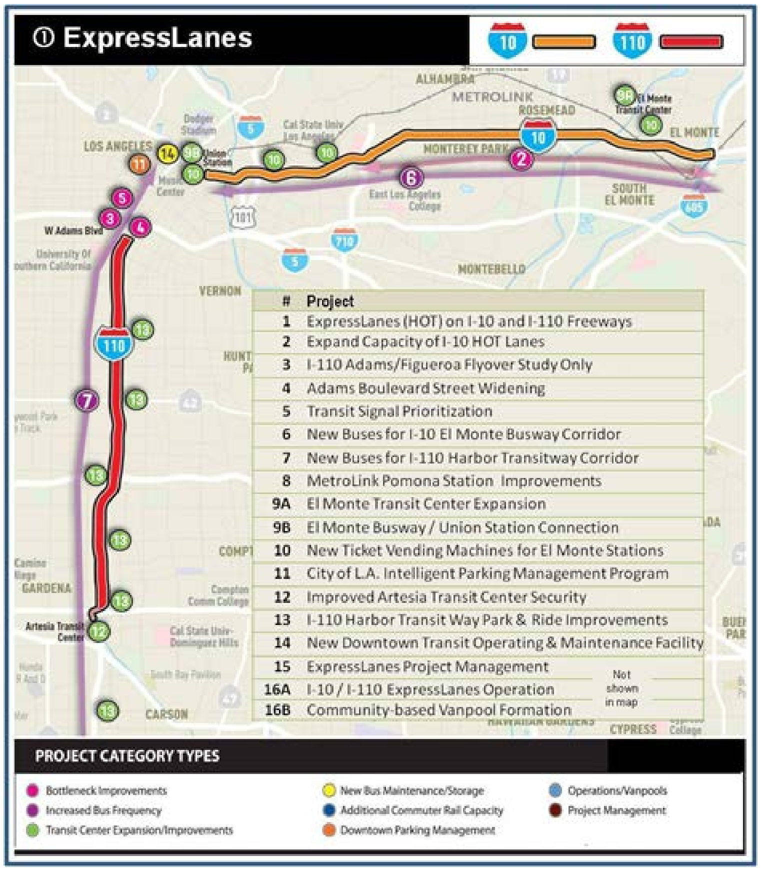


**Figure 5-9: Los Angeles County CRD Deployment Area (*Source: U.S. DOT, Los Angeles Congestion Reduction Demonstration, 2010, [48]*)**

### Hypotheses

The following are tolling-related hypotheses:

- The HOT lanes will regulate vehicular access to the I-10 and I-110 and improve their operation.
- Some general-purpose lane travelers will shift to the HOT lanes, while HOV lane travelers will continue to use them after they are converted to HOT.
- After ramp-up, the HOT lanes on I-10 and I-110 pricing will maintain operating improvements on I-10 and I-110.
- The downtown IPM project will result in 70-90% of the parking spaces on each block occupied throughout the day.
- The downtown IPM project may increase parking revenues that can be used to fund system expansion in other high-demand areas.

The evaluation plan also includes hypotheses developed for technology, transit, TDM, congestion, safety, equity, environmental impacts, etc. [48].

**Performance Measures**

The following are a few key measures that will be used to test the hypotheses:

- Travel time and travel speeds
- Travel time savings on HOV/HOT lanes compared to general purpose lanes
- Travel time reliability (buffer index, planning index)
- Throughput (vehicle, person)
- Emission factors for criteria and greenhouse gases (GHG)
- Fuel consumption factors
- Percentage of respondents who perceive a reduction in congestion

Additional measures are available in the Test Plans.

**Evaluation Approach**

A before (pre-deployment) and after (post-deployment) data collection approach will be used to evaluate the impacts of the CRD projects. Preliminary approaches are available in the Test Plans. A Final Evaluation Report, which will discuss the evaluation approach and results, is forthcoming.

According to the Test Plans, the Final Evaluation Report will include findings related predominantly to safety and transit system data. Although the programs are not specifically designed to improve safety and therefore safety data is not a top priority of the program, safety data will be measured to assess whether safety impacts have worsened, improved, or not changed. The safety analysis will include both before and after comparisons of general crash and incident data to measure the safety of the HOT lanes and HOT lane access control features. Data collected for safety will include: total number of crashes, spatial configuration of crashes, types and severity of crashes, crashes per 1,000 VMT, and frequency of buffer and transition zone violations and crashes. The report does not indicate whether the analysis will monetize these findings. If the analysis is to do so, potential methods include multiplying the change in crashes by the value of statistical life (or for less-severe crashes, the value of injuries), as is done in other UPA scenarios described above.

The impacts to transit system performance will use recorded data (i.e., ridership) as well as information from surveys and interviews. These impacts will be measured by aggregate corridor revenue miles, park-and-ride lot capacity, average travel time, average travel speed, and on-time performance. Together, these data will allow the analysis to quantify total person throughput on transit systems, changes in mode share/ridership across transit measures, and therefore to quantify impacts to traffic congestion. Travel time and transit reliability metrics will also inform the equity analysis, though the report does not indicate if, and how, the analysis will quantify and/or monetize those impacts.

The analysis also proposes to include qualitative descriptions of the outreach and marketing impacts for the program. Although the report does not specify exactly how the metrics will be reported (including whether they will be quantified), content analysis includes assessing public reaction to the project, chronicling project hurdles and challenges, and evaluating methods used to overcome the hurdles and challenges. The outreach materials, activities, documents, and media coverage will be stored and analyzed using NVivo, a quantitative analysis software owned by QSR International.

**Data**

The Test Plans have outlined the data sources, data availability, methods of data collection and analysis, and project risks. The Final Evaluation Report will discuss the data collected. Pre-deployment data was collected from July 2009 to December 2010. Post-deployment data was collected between July 2010 and December 2011.

**Key Findings**

The Final Evaluation Report was not finalized and published before the release of this research effort.

**Challenges and Issues**

The Final Evaluation Report will discuss challenges, issues, and lessons learned. In the initial reports, the analysis understands that in many cases, exogenous factors may have a potentially significant impact on the study findings, and that the quantitative analysis may not be able to avoid such scenarios. This presents a significant challenge to the analysis.

#### *5.2.1.2 Integrated Corridor Management (ICM)*

The Integrated Corridor Management (ICM) Initiative was started by the U.S. DOT to improve safety and mobility within corridors, and to advance the development and deployment of ICM systems throughout the U.S. The ICM Initiative is jointly sponsored by the ITS Joint Program Office, Federal Highway Administration (FHWA), and Federal Transit Administration (FTA). The ICM Initiative is now in the demonstration phase, which includes two field deployments of specific ICM concepts, one on the US Route 75 (US-75) corridor in the Dallas, and another on the Interstate 15 (I-15) corridor in San Diego. Prior to demonstration, the U.S. DOT sponsored the assessment of ICM strategies in Dallas and San Diego using analysis, modeling, and simulation (AMS) approaches to assist the sites in selecting the most cost-beneficial strategies. The U.S. DOT is also sponsoring the evaluation of the two field demonstration efforts. For more information on the implementation of ICM AMS methodology, refer to Traffic Analysis Toolbox Volume XIII [96].

### 5.2.1.2.1 ICM National Evaluation

The national evaluation of the ICM demonstrations is underway, and documentation, including plans are still being finalized. The information included here should be viewed as preliminary information that will change. The evaluations were initiated in August 2010 and are expected to be completed by summer 2015.

**Evaluation Goal**

The national evaluation will investigate the impacts of the ICM deployments in Dallas and San Diego, including the implementation of specific agency operational capabilities and traveler behavior, mobility, safety, air quality and benefit-cost impacts associated with the exercise of those capabilities. The evaluation will also explore the institutional and organizational issues and lessons associated with the two ICM deployments.

The evaluation will assess if the ICM efforts will:

- Improve Situational Awareness

- Enhance Response and Control
- Better Inform Travelers
- Improve Corridor Performance
- Positive or No Impact on Safety
- Positive or No Impact on Air Quality
- Have Benefits Greater than Costs
- Provide a Useful and Effective Tool for ICM Project Managers

**Performance Measures**

The as-yet-unpublished Final Evaluation Report will discuss the performance measures that will be estimated.

**Evaluation Approach**

The National Evaluation Framework sets up the initial assumptions for a benefit-cost analysis (BCA) model for ICM technologies in San Diego and Dallas. First, the framework outlines how safety, mobility and air quality impacts will be modeled and quantified. Next, the framework assumes that the outputs of the models will be inputs into the BCA analysis. The ICM strategies evaluated include adding transit capacity and providing en-route traveler information.

The BCA model uses general study parameters (e.g., crash-reduction rates, mobility impacts, and ICM cost elements) and monetizes the impacts by leveraging external data (e.g., crash cost data, value of travel time savings). To do this, the BCA relied on four primary sources of data, including:

- ICM-related cost data from state and local agencies (Dallas and San Diego ICM deployers) responsible for capital expenditures and operations and maintenance (O&M) of ICM equipment
- Quantified outcomes from the ICM Corridor Mobility, Air Quality, and Safety Analyses:
    - *Travel time savings:* Travel time savings will be assigned to both personal travel and freight transportation as the result of reduced congestion. Estimates include vehicle based and per-person or per-trip estimates on both the corridor and facility level and by mode of transit.
    - *Travel time reliability:* Benefits from travel time reliability depend on travel time and standard deviation of travel time. Estimates include changes in travel time index, 95th percentile travel time, standard deviation of travel time, planning time, planning time index, buffer index and transit on-time performance by mode and corridor.
    - *Delay reductions:* Includes changes to total vehicle delay and total person delay for different types of roadways (corridor-wide, freeway, HOV lanes, and arterials). Also includes delay reductions from improved incident management.
    - *Throughput:* Includes changes to transit ridership, vehicle throughput, person throughput, VMT, and incident related throughput for different types of roadways (corridor-wide, freeway, HOV lanes, and arterials).
    - *Safety impacts:* Safety impacts are categorized into three areas: incident management, crashes and incidents, and safety perception. Safety benefits are not likely to have a direct, measurable effect, especially given the one year time frame.
    - *Air quality impacts:* These impacts are calculated using the change in emissions (by pollutant) as modeled by the EPA MOVES Model.

- Literature used to monetize benefit elements:
  - *Crash Costs*: The analysis proposes to use Blincoe et al [53], or US DOT guidance [54] to value the cost of a crash ($6.2 million). The cost of the crash will vary with the severity of the crash (from no injury to fatality).
  - *Motor vehicle operating costs*: The analysis proposes to use AAA-reported operating cost estimates (16.74 cents per mile).
- Federal, state and regional government guidance:
  - *Travel time savings*: For passengers, the analysis proposes using the opportunity cost estimates reported by the US DOT- ($14.32 per hour) or site specific AMS-reported values ($16.01 per hour for Dallas and $24 per hour for San Diego). For travel time savings for freight transportation, the analysis proposes using productivity estimates from FHWA-reported values ($23.15 per hour). American Trucking Association (reported profit), or Federal Motor Carrier Safety Administration (reported profit).
  - *Travel time reliability*: Monetization estimates are still an emerging science and are dependent on location, purpose, and time of travel. Monetization estimates will be determined in the site-specific benefit-cost analysis test plans.
  - *Fuel prices*: The analysis proposes to use values reported by the US Department of Energy's Energy Information Administration ($3.14 per gallon for gasoline and $3.16 per gallon for diesel in San Diego and $2.69 per gallon for gasoline and $2.94 per gallon for diesel in Dallas).
  - *Air quality impacts:* The impacts will be calculated using the change in emissions (by pollutant) and cost per ton assigned to each pollutant. The model assumes the locality based pollutant values assigned by the EPA MOVES Model.
  - *Discount rate:* The discount rate used in the analysis will be 7 percent, and is determined according to Office of Management and Budget (OMB) Circular A-94.

**Data**

The Final Evaluation Report will discuss the data collected.

**Key Findings**

The Final Evaluation Report will discuss the findings and results.

**Challenges and Issues**

- *Quantifying and Monetizing Benefits:* The estimation of the ICM benefits will be computed using a before and after analysis. It may be difficult to directly link the benefits to ICM technologies due to other influences on the corridor during these time periods. Forecasting future costs and benefits requires multiple assumptions about trends, policies, and prices, among others. Over the 10-year time horizon of this analysis, the assumptions can greatly influence the estimated costs and benefits. Due to overlapping technologies and systems, difficulties may arise in data collection, duplication, delays, and the inability to separate out costs and benefits

#### 5.2.1.2.2 ICM AMS Dallas

**Evaluation Goal**

The goal of the 2012 AMS effort was to estimate the benefits and costs of deploying ICM strategies along the US 75 corridor in Dallas, TX. This was intended to help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion [55, 56].

The ICM strategies that are included in the model are:

- Comparative travel time information (pre-trip and en-route)
- Incident signal retiming plans for arterials
- Incident signal retiming plans for frontage roads
- Light-Rail Transit (LRT) smart parking system
- Red Line capacity increase
- LRT station parking expansion through private and valet parking

Figure 5-10 shows the Dallas ICM AMS study area.

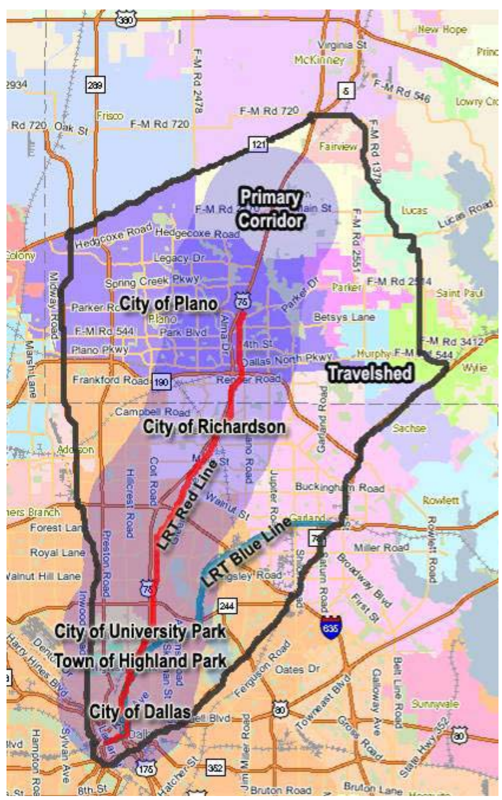


**Figure 5-10: Dallas ICM Study Area (*Source: Cambridge Systematics, 2010, [55]*)**

**Hypotheses**

The key hypothesis of this study was that effectiveness ICM strategies would vary under different prevailing conditions. ICM would result in increased travel time reliability, throughput, and reduced travel times, fuel consumption, and emissions.

**Performance Measures**

- Mobility
  - Person Miles Traveled
  - Person Hours Traveled
  - Throughput
  - Total Delay (in person hours)
  - Average Delay (minutes/traveler)
  - Average travel time (minutes/traveler, for the length of the entire corridor)
  - Planning Index (ratio of the $95^{th}$ percentile travel time to the zero-delay travel time for each trip)
  - Variance in travel time (minutes)
- Transit
  - Ridership
  - Transit capacity utilization (expressed as a percentage)
  - Park-and-ride parking lot users
  - Parking lot utilization (expressed as a percentage)
- Environmental
  - Estimated fuel savings
  - Estimated emissions
- Institutional and Organizational Analysis (Agency Efficiency)
  - Breadth of Partnerships
  - Improved Decision-making
  - Degree of Formalization
  - New and Improved Capabilities
  - Enhanced Sustainability
  - Changes in Institutional Behavior
  - Lessons Learned
- User Satisfaction
  - Changes in peak period travel behavior (mode, route, timing, frequency, etc.) due to conditions in the corridor and due to improved traveler information
  - Changes in satisfaction regarding travel/trip experiences in the corridor
  - Ability of travelers to detect improvement in the quality of service in the corridor
  - Changes in awareness of traveler information sources
  - Changes in reported utilization of (frequency, method, timing, etc.) traveler information sources
  - Changes in satisfaction regarding traveler information/sources

**Evaluation Approach**

Within the US 75 corridor, the AMS methodology applied included manipulation of macroscopic trip table to determine overall trip patterns; and mesoscopic analysis of the impact of driver behavior in reaction to ICM strategies (both within and between modes). The use of microsimulation modeling was initially considered for assessing arterial traffic signal coordination, but due to the lack of comprehensive existing microscopic simulation networks, it was decided to use DIRECT, a mesoscopic traffic simulation model developed by Southern Methodist University (SMU). DIRECT has the ability to represent signal operations.

The following assumptions were made:

- Awareness and use of both pre-trip and en-route traveler information would increase by 10 percent from pre-ICM to post-ICM deployment.
- Transit ridership increased by 10 percent.
- Coordination of signal retiming plans between the cities of Dallas, Plano and Richardson would increase throughput by 15 percent.
- Value of time was assumed to be $12.00 per hour for both cars and trucks.
- Travel costs were considered to be $0.25 per mile, with tolls being an additional $0.10 per mile.
- Transit costs were assumed to be $1.00 per ride.

The evaluation used these data to conduct a benefit-cost analysis (BCA) of the ICM scenario over a 10-year lifecycle. In order to arrive at an average annual daily performance measurement, the performance measures from the different operating scenarios are combined by weighting them based on the probability of their occurrence. The overall benefit of ICM is determined by the difference in these average annual daily performance measurements from the “with ICM” to “without ICM” scenarios, calculated as the net present value (NPV) over a 10-year lifecycle using a 7 percent discount rate.

Agency efficiency performance was analyzed via a baseline standardized survey of transit operators, while user satisfaction results were obtained through surveys of system travelers.

The BCA model uses general study parameters (e.g., crash-reduction rates, mobility impacts, and ICM cost elements) and monetizes the impacts by leveraging external data (e.g., crash cost data, value of travel time savings). To do this, the BCA relied on four primary sources of data, including:

- ICM-related cost data from the deployers that are responsible for capital expenditures and operations and maintenance (O&M) of ICM equipment:
  - *Technology costs:* Includes the implementation, O&M, and reinvestment costs for equipment such as DSS, enhancement of the SmartNET regional information exchange network, arterial street dynamic message signs, upgrades to traffic signal systems, the arterial street monitoring system, various supporting transit improvements (e.g., mobile data terminals), parking management systems, and others.
  - *Vehicle operating cost savings*: Includes fuel and non-fuel-related costs. These are obtained through supplemental literature (explained in bullet below).
- Quantified outcomes from the ICM Corridor Performance, Air Quality, and Traveler Response Analyses:
  - *Travel time savings (person hours traveled):* For freight transportation and personal travel, travel cost savings are determined by the opportunity cost of lost productivity associated with congestion. The analysis uses standard data from NCTCOG.

    - *Air quality impacts:* These impacts are calculated using the change in emissions (by pollutant) and cost per ton assigned to each pollutant. This uses the social cost of carbon, as identified by U.S. EPA, and the EPA MOVES Model.
    - *Safety impacts*: To identify benefits to safety, the analysis calculates the reduction in the number and severity of incidents by incident type, and then connects this to public data on crashes and the associated costs. Crash costs include property damage, lost productivity, medical costs, travel delay, legal costs, emergency services, insurance costs, costs to employers, and others, and are based on the severity of a crash. Fatal crashes incorporate the Value of a Statistical Life (VSL), as determined by the U.S. DOT. Non-fatal injury costs are estimated based on the fraction of a VSL suffered in terms of pain, suffering, reduced income and loss of quality of life, determined on a scale from "minor" to "fatal." This scale is developed using input from panels of experienced physicians.
    - *Travel time reliability*: Travel time reliability is based on motorist's willingness to pay (WTP) for greater predictability of trip durations. The analysis notes that it will be calculated as the change in standard deviation of trip travel times identified in the mobility analysis and the local value of travel time.
- Literature used to monetize benefit elements:
    - For travel time savings, the analysis uses inputs from NCTCOG. The opportunity cost of lost productivity is estimated at $17 (in 2007 dollars) for freight transportation and $14 (in 2007 dollars) for personal travel.
    - For fuel prices and non-fuel costs, the analysis uses inputs from *NCTCOG*. Fuel prices use market rates (and projections) for vehicle fuel prices. Non-fuel-related costs (e.g., tires) were estimated to be 15 cents per mile in 2007 dollars.
    - For non-injury crash costs (property damages and travel cost delays), the analysis uses estimates from Blincoe et al [53] adjusted to 2011 dollars [15].
- Federal, state and regional government guidance.
    - *Social Cost of Carbon (SCC):* The SCC is determined by the U.S. EPA. In 2007, for example, the cost of one metric ton of CO2 pollution was estimated to be $21. The EPA MOVES Model incorporates these unit-cost emissions values to determine the total cost savings associated with a specified change in driver behavior.
    - *Value of a Statistical Life (VSL):* The U.S. DOT estimated the Value of a Statistical Life (VSL) to be $6 million in 2009. For the analysis, fatal accidents incur this cost per person, whereas the costs of non-fatal accidents are determined using a disutility factor based on the severity of the accident ranging from 0.002 for minor injury severity level to 0.76 for critical injury severity level. These fractions are estimated in the DOT provided guidance. These numbers are based on previous guidance provided by DOT, the current guidance puts the VSL at $9.1 million and uses slightly different fractions of the VSL for injury severity levels [54].
    - *Discount rate:* The discount rate used in the analysis is 7 percent, and is determined according to Office of Management and Budget (OMB) Circular A-94.

**Data**

The data for this study comes primarily from the regional travel demand model maintained by the North Central Texas Council of Governments (NCTCOG), Dallas' metropolitan planning organization (MPO). NCTCOG maintains the regional travel demand model in TransCAD, with 1999 being the most recent validation year. NCTCOG model was used as the primary source for the vehicular trip tables and networks utilized by DIRECT. In addition, available coefficients (e.g., value of time, operating cost per mile, etc.) and variables from the travel demand model were reviewed and adjusted for incorporation into the to the generalized cost equation within DIRECT. The Dallas AMS team utilized the DART on-board survey to develop an estimate of the transit origin-destination (OD) trip table.

**Key Findings**

- Estimated benefit/cost ratio for the ICM deployment over the 10 year lifecycle of the project is approximated at 20.4:1.
  - ICM deployment on the US 75 corridor will produce $16.5 million in user benefits per year. Over the 10-year life cycle of the ICM systems, total benefit would be $278.8 million.
  - Costs to deploy ICM on the US 75 Corridor are estimated to be $1.62 million annualized over the 10-year life cycle of the project. The total life-cycle cost to deploy the ICM system is estimated at $13.6 million.
- Expected annual savings include 740,000 hours of person-hours of travel, a reduction of fuel consumption by 981,000 gallons of fuel, and an annual reduction of 9,400 tons of vehicular emissions.

**Challenges and Issues**

- *Technical Performance:* The only extra capacity in the corridor is available through rail transit. Additional detection is needed for improved real-time arterial data. Inconsistencies, duplication and delays in data are risks affecting data collection and analysis.
- *Driver Acceptance:* Some users may experience disbenefits. For example, during a freeway incident ICM response plans may decrease arterial green time on cross streets in favor of additional green time on diversion routes that are parallel to the freeway.
- *Quantifying and Monetizing Benefits:* The ability to distinguish results from ICM-enabling technologies is sometimes difficult given that ICM technologies do not operate in isolation. The holistic and comprehensive nature of the “system” causes difficulties in assigning benefits and costs directly to the system, as opposed to external factors that cannot be controlled for. Forecasting future costs and benefits requires including multiple assumptions about trends, policies, and prices, among others. Over the 10-year time horizon of this analysis, the assumptions can greatly influence the estimated costs and benefits. Similarly, estimating agency-related costs over a 10-year time period is difficult. Lastly, the monetization of the VSL and injury severity level uses outdated DOT guidance.

### 5.2.1.2.3 ICM AMS San Diego

**Evaluation Goal**

The goal of the 2012 AMS effort was to estimate the benefits and costs of deploying ICM strategies along I-15 corridor in San Diego, CA. This was intended to help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion [57].

The ICM strategies that are included in the model are:

- Pre-Trip Traveler Information
- En-Route Traveler Information
- Freeway Ramp Metering

- Signal Coordination on Arterials with Freeway Ramp Metering
- Physical Bus Priority
- Congestion Pricing on Managed Lanes

Figure 5-11 shows the San Diego ICM AMS study area.

**Hypotheses**

The key hypothesis of this study was that the effectiveness of ICM strategies would vary under different prevailing conditions. ICM would result in increased travel time reliability, throughput, and reduced travel times, fuel consumption, and emissions.

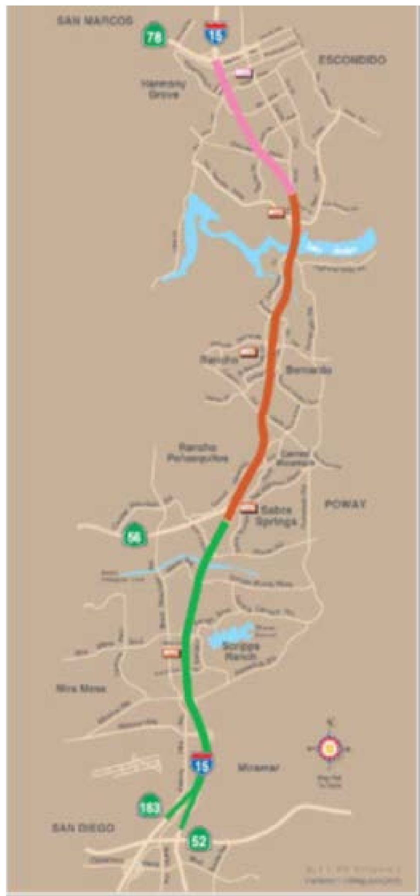

**Figure 5-11: San Diego ICM Study Area (*Source: Cambridge Systematics, 2010, [57]*)**

**Performance Measures**

- Mobility
  - Travel time
  - Delay
  - Throughput (vehicle, person)
- Reliability (planning time index)
- Emissions and fuel consumption – estimated based on IDAS methodology

- Institutional and Organizational Analysis (Agency Efficiency)
  - Breadth of Partnerships
  - Improved Decision-making
  - Degree of Formalization
  - New and Improved Capabilities
  - Enhanced Sustainability
  - Changes in Institutional Behavior
  - Lessons Learned
- User Satisfaction
  - Changes in peak period travel behavior (mode, route, timing, frequency, etc.) due to conditions in the corridor and due to improved traveler information
  - Changes in satisfaction regarding travel/trip experiences in the corridor
  - Ability of travelers to detect improvement in the quality of service in the corridor
  - Changes in awareness of traveler information sources
  - Changes in reported utilization of (frequency, method, timing, etc.) traveler information sources
  - Changes in satisfaction regarding traveler information/sources

**Evaluation Approach**

The analysis of the corridor was conducted using the microscopic modeling part of the TransModeler software package. The model was calibrated to 2003 data, and extrapolated to produce a 2012 baseline.

Following assumptions were made:

- VMT would increase by five percent in 2012 (compared to 2003)
- En route traveler information market adoption would increase to 30 percent (up from an assumed 5 percent in the 2003 baseline year)
- During a major incident, managed lanes on I-15 would be opened to all traffic to maximize throughput

In order to arrive at an average annual daily performance measurement, the performance measures from the different operating scenarios are combined by weighting them based on the probability of their occurrence. The overall benefit of ICM is determined by the difference in these average annual daily performance measurements from the “with ICM” to “without ICM” scenarios. Agency efficiency performance measurements were analyzed via a baseline survey of transit operators, while user satisfaction results were obtained through surveys of system travelers.

The analysis of the San Diego ICM study area includes an analysis of the benefits, costs, and net benefits. The following sections outline the methodology used.

<u>Benefits</u>

The analysis first monetized the benefits associated with four performance measures, including: travel time, travel time reliability, fuel consumption, and emissions. Deployment of ICM system produces $13.7 million in benefits per year, or $115.9 million over the 10-year life-cycle of the analysis.

To begin, the analysis identified performance measures associated with the baseline (i.e., non-ICM) and with each of the ICM alternatives for the AM peak period. The difference between the baseline and each scenario accounted for one-half of the daily benefit (or "disbenefit" where the ICM degraded throughput), assuming that the PM peak period is anticipated to yield the same benefits. The analysis then multiplied these benefits/disbenefits by 260 workdays to identify the annual impact.

Expected annual savings include 245,594 hours of vehicle-hours of travel, a reduction of fuel consumption by 322,767 gallons of fuel, and an annual reduction of 3,057 tons of vehicular emissions. To monetize these impacts, the analysis utilized external information, such as market prices or per-unit metrics according to guidance. These include:

- Travel times savings (hours), including for travel time and travel time reliability, was multiplied by $24 per hour (the average value of time for the test corridor area). The analysis views this figure as a conservative value for travel time reliability, noting that typically travel time reliability is valued at 2.5 to 3 times the average value of travel time. The report however, did not provide a source for this estimate.
- Fuel savings (in gallons) were multiplied by $4.00 per gallon, which was the market rate for a gallon of gasoline in the region at the time of the study. The report however, did not provide a source for this estimate.
- Emissions foregone were multiplied by the emission cost per mile per speed category. The report however, did not provide a source for this estimate.

Other input metrics were also used in the analysis, as included below. The study did not include data sources for these metrics. These metrics include the following:

- BRT Cost, or the BRT fare in terms of dollars per ride: $5 per ride.
- Auto Operating Cost, or the driver cost per mile: $0.42 per mile.
- BRT Off-Vehicle Travel Time, or the estimated traveler time spent outside a BRT if the traveler decides to shift from driving to BRT riding. It includes the time that the traveler spent accessing the BRT station, waiting for a BRT, and exiting the BRT station at the destination station: 20 minutes.
- Auto Off-Vehicle Travel time, or the estimated traveler time spent outside his/her vehicle if the traveler decides to continue driving: 0 minutes.
- BRT In-Vehicle Travel Time, or the estimated traveler time spent inside a BRT, assuming the BRT will travel at an average speed of 60 mph: BRT route distance (miles) per 60 mph.
- Auto In-Vehicle Travel Time, or the estimated traveler time spent inside the vehicle he/she is driving: this value is extracted from the simulation model.
- Standard Value of Travel Time, or the value of travel time used in calculating the monetary value of travel time savings, based on driver income: $0.40 per minute ($24 per hour).
- Toll Rate, or the per-mile toll that is charged to SOVs at any time irrespective of the level-of-service on general purpose and managed lanes: $0.10 - $1.00 per mile.

<u>Costs</u>

The ICM Test Corridor study calculated average costs consistent with the ITS National Architecture, including capital and operations and maintenance (O&M) costs. The up-front capital cost for the ICM deployments is approximately $7.55 million; annual O&M costs are estimated to be $0.53 million per annum. Assuming a 10-year life cycle for all components, the ICM system cost is estimated to be $1.42 million per year, or $12.0 million over the 10-year life-cycle.

In the analysis, capital costs included up-front costs necessary to procure and install ITS equipment, estimated as a total (one-time) expenditure. Capital costs include “soft costs” (e.g., design and installation) in addition to the cost of equipment. Operations and maintenance (O&M) costs, presented as annual estimates, include the costs necessary to operate and maintain the deployed equipment, as well as the associated labor costs. O&M costs exclude replacement of the equipment at the end of its useful life.

The analysis then combines capital and O&M costs to estimate an annualized total cost for the ICM improvement. The annualized cost represents the average annual expenditure that would be expected in order to deploy, operate, and maintain the ICM improvement, and replace the equipment as they reach the end of their useful life. To do this, capital costs are amortized over the anticipated life of each piece of capital equipment. The amortized annual capital cost combined with the annual O&M cost provides the annualized total cost.

Net Benefit/Disbenefit

Benefits of ICM deployment are estimated to be $13.7 million per annum, or a total of $115.9 million (annualized) over 10 years. Costs of the deployment, including capital and operations and maintenance (O&M) are estimated to be $1.42 million per year, or $12.0 million over 10 years. Therefore, the estimated benefit/cost ratio of the ICM deployment over the 10 year life cycle of the project is approximately 9.7:1.

**Data**

The main source of data for the analysis is derived from the PeMS database, which provided traffic count and incident data for determining the 2003 baseline, as well as the probability of occurrence for each of the simulated scenarios.

**Key Findings**

- ICM strategies produce more benefits at higher levels of travel demand, and during non-recurrent congestion.
  - Approximately 93 percent of the total ICM benefits result from the high- and medium-demand scenarios (representing 69 percent of commute days).
  - Two-thirds of the total benefit is attributed to high and medium-demand scenarios with an incident.
  - For individual travelers who primarily rely on the I-15 southbound facility the majority of benefits accrues under particular operational conditions associated with high travel demand and incidents. This finding validates the hypothesis that ICM is most effective under the worst operational conditions including heavy demand and major incidents.
- Estimated benefit/cost ratio for the ICM deployment over the 10 life cycle of the project is approximated at 9.7:1.
  - Deployment of ICM on the I-15 Corridor produces $13.7 million in user benefits per year. Over the 10-year life cycle of the ICM systems, benefits produced a total benefit of $115.9 million.

- Costs to deploy ICM on the I-15 Corridor are estimated to be $1.42 million annualized over the 10-year life cycle of the project. The total life-cycle cost to deploy the ICM system is estimated at $12.0 million.

**Challenges and Issues**

- *Technical Performance:* It is challenging to obtain timely, high quality transportation data that can be integrated across different operational conditions for freeways, arterials, and transit. Additional detection is needed for improved real-time arterial data.

#### *5.2.1.3 Automotive Collision Avoidance Systems (ACAS) Evaluation*

**Evaluation Goal**

The Automotive Collision Avoidance System field operational test (ACAS FOT) project was led by General Motors (with Delphi playing a major supporting role) under a cooperative agreement with the U.S. DOT. The goal of the FOT was to examine the suitability of ACAS for widespread deployment from the perspectives of both driving safety and driver acceptance [58].

**Hypotheses**

The collision warning system will provide warnings to the driver, rather than taking active control of the vehicle, and performance will be sufficiently reliable and robust to support a meaningful field operational test.

**Performance Measures**

- Driver acceptance and perceived safety benefits
- Driver behavior

**Evaluation Approach**

The FOT involved exposing a fleet of 11 ACAS-equipped Buick LeSabre passenger cars to 12 months of naturalistic driving by lay drivers from southeastern Michigan. The ACAS system included both a forward crash warning (FCW) system and an adaptive cruise control (ACC) system.

The FCW and ACC functions were implemented using a combination of (a) a long-range forward radar-based sensor that is capable of detecting and tracking traffic, (b) a forward vision-based sensor that detects and tracks lanes and (c) GPS and a map database to help ascertain road geometry.

Following trials, study participants were asked to respond to a set of 35 questions, including willingness to pay for the ACAS. After experiencing the FCW feature for three weeks, 36 percent of respondents indicated that they “probably or definitely” would purchase FCW with a new vehicle for an additional cost of $1,000.

The analysis conducted following the Field Operation Test (FOT) indicated multiple benefits for the ACAS system, including predominantly those potentially related to a reduction in crashes. For example, drivers were found to stay behind a given preceding vehicle for approximately twice as long when ACC was engaged; headway time (e.g., distance traveling behind lead vehicle) is found to increase by statistically significant amounts during periods of quasi-steady-state vehicle-following, and drivers appeared to adjust their following distances to allow extra distance on limited-access roads. Similarly, ACAS appears to induce the practice of staying in one's own lane, and ACAS drivers are more likely to increase the distance between a lead vehicle when conducting a "flying-pass" maneuver (i.e., speeding up to pass a vehicle before reaching a lead vehicle in one's own lane). The tests also found that the brake is applied 20 times less-frequently per distance traveled when using the ACAS system.

While many potential benefits are considered throughout this study, none are quantified or monetized. For example, these findings suggest that ACAS may reduce vehicle crashes, congestion/traffic, and fuel use. However, the study does not indicate the number of crashes potentially reduced, the hours of congestion mitigated by the system, or the fuel savings associated with more controlled driving with less braking. Had these metrics been quantified, unit-costs such as dollars per vehicle accident, dollars per hour of congestion, and dollars per gallon of gasoline, could inform a cost-benefit analysis of the ACSA system.

**Data**

During the FOT which began in June 1999 and ended in November 2004, ninety-six drivers participated in the project, with an accumulated 137,000 miles driven. Data collected included data from on-board vehicle instrumentation and videos of the forward driving scene and the driver's face. Driver behavior was analyzed and compared to data collected from post-drive questionnaires, interviews, and focus groups.

**Key Findings**

- ACC widely accepted by drivers.
  - Low traffic safety issue with ACC, but possible benefits due to reduction in headways (1 second) and reduction in passing behavior.
- FCW acceptance was mixed due to false alarms, and was not found to be significantly related to FCW alert rate.
  - FCW may have contributed to a timely driver response to an emerging rear-end crash conflict, but frequency or magnitude of such conflicts in manual driving was unchanged.
  - Headways in manual driving with FCW enabled were found to increase on freeways and during daytime driving.
- Willingness to pay for the ACAS system installed in a new vehicle shows that 36% of drivers would pay $1,000 for the system.
- Recommendations made by drivers for changes to ACC system:
  - Onset of braking and acceleration should be more gradual,
  - Greater acceleration requested for passing maneuvers, and
  - Change number of headway settings.

**Challenges and Issues**

- *Technical performance*: Difficult to make the system free of false alarms in a real world traffic environment.

- *Driver acceptance*: Acceptance of systems based on short-term exposures can be misleading; large FOT investments will benefit from comparable investment in data mining and analysis.
- *Quantifying and Monetizing benefits*: Many of the potential benefits associated with this system are a result of changes in driver behavior. Similarly, it is difficult to identify where a driver reacted as a result of the ACAS, and where they acted independently. Simply put, it is difficult to quantify the reduction in vehicle crashes, congestion/traffic, and fuel use that is attributable to the ACAS system. If quantified, these metrics could be monetized using government guidance for crash costs (DOTs VSL and severe injury scale), the opportunity cost of travel time (DOTs guidance on the value of travel time), and fuel savings (using the current price of fuel and/or quantifying the emission reductions using the EPA MOVES model).

#### *5.2.1.4 Integrated Vehicle-Based Safety Systems (IVBSS) Program: Light-Vehicle and Heavy-Truck Field Operational Tests*

**Evaluation Goal**

The IVBSS program is a cooperative agreement between the United States Department of Transportation and a team led by the University of Michigan Transportation Research Institute. The objective of the program was to develop a prototype integrated, vehicle-based, crash warning system that addressed rear-end, lateral drift, and lane-change/merge crashes for light vehicles (passenger cars) and heavy trucks (Class 8 commercial trucks), and to assess the safety benefits and driver acceptance of these systems through field operational test [59].

**Hypotheses**

Integrated crash warning systems offer the potential to provide comprehensive, coordinated information, from which the individual crash warning subsystems can determine the existence of a threat and provide an appropriate warning to drivers.

**Performance Measures**

- Driver acceptance
- Driver behavior
- Lane-keeping, lane departures, and turn-signal use

**Evaluation Approach**

Three crash-warning subsystems were integrated into both light vehicles and heavy trucks: forward-crash warning, lateral-drift warning, and lane-change/merge crash warning.

Separate data analysis plans were developed for each vehicle platform (light and heavy vehicles) to evaluate impacts with and without IVBSS.

In-vehicle equipment was used to capture detailed data on the driving environment, driver behavior, warning system activity, and vehicle kinematics. Post-drive surveys and debriefings were used to assess driver acceptance. In general, respondents viewed IVBSS as beneficial to safety, with most noting that they would recommend the system to others and would purchase the system themselves.

Based on willingness to pay, light-duty vehicle drivers are willing to purchase an IVBSS system with their vehicle for $750.

Despite conducting rigorous statistical analyses on the driver-based data, the analysis stopped short of monetizing potential benefits (or costs) related to changes in driver behavior. For example, for light-vehicles, the analysis found there to be a statistically significant effect on the frequency of lane departures (from 14.6 per 100 miles to 7.6 per 100 miles). Similarly, drivers reported increased use of turn-signal use due to IVBSS. These findings related to lane departures and turn signal use could be used to quantify reductions in crashes, increase in safety, and other accident-related metrics. Using crash data (to identify the monetary costs associated with a crash) and other safety-related metrics (e.g., VSL), this data could then be used to monetize benefits associated with the system.

**Data**

The heavy-truck field test began in February 2009, with 20 participants that represented a sample of commercial drivers from the participating freight carrier's fleet. The heavy-truck field test was completed in December 2009, after approximately 10 months of continuous data collection.

The light-vehicle field test began in April 2009, and was completed in May 2010. The field test collected naturalistic data from 108 licensed drivers, over 12 contiguous months, using 15 instrumented passenger cars.

With the exception of having slightly fewer drivers than expected in the heavy-truck field test, both field tests followed test plans that had been developed at the beginning of the program.

**Key Findings**

Key findings indicate that use of IVBSS resulted in improvements in lane-keeping, fewer lane departures, and increased turn-signal use. No negative behavioral-adaptation effects of using the integrated system were observed in either driver group.

- For light vehicles, the integrated system had a statistically significant effect on the frequency of lane departures, decreasing the rate from 14.6 departures per 100 miles during baseline driving to 7.6 departures per 100 miles during the treatment condition.
- For heavy trucks, the integrated crash warning system had no effect on lane departure frequency, but a trend towards a decrease in lane departures was observed for 13 of the 18 drivers.
- Majority of drivers reported that their driving behavior changed as a result of using the integrated system. The most frequently mentioned change was an increase in turn-signal use, which was the result of receiving lane departure warnings triggered when drivers made un-signaled lane changes.
- In general, respondents viewed IVBSS as beneficial to safety, with most noting that they would recommend the system to others and would purchase the system themselves. Based on willingness to pay, light-duty vehicle drivers are willing to purchase an IVBSS system with their vehicle for $750.

**Challenges and Issues**

- *Technical Performance:* Questions still remain about how the provision of multiple warnings will be arbitrated by the system when multiple threats are detected (which one will be presented first) or when multiple applications (lane departure, lane change/merge, forward collision, curve speed, etc.) are installed. It is unclear if warnings are still effective if provided in series.
- *Driver Acceptance:* Interfaces, and warning strategies, vary widely. Additional human factors testing related to the use of audio, visual and haptic modalities needs to be completed, as well as a comparison of "warning only" versus "warning and intervening" strategies.
- *Quantifying and Monetizing Benefits:* To monetize the benefits of lane reductions and increased turn signal use, there needs to be sufficiently robust data on the benefits these actions provide. Currently, minimal data exists. First, there is likely insufficient information to quantify the number of accidents that the system itself would reduce, given that there is not a perfect one-to-one relationship of warning signals to crashes prevented. Nonetheless, increased testing and data may allow for such a ratio-based calculation. Furthermore, minimal data exists that assesses the reduction in crashes (and therefore the reduction in crash-related expenditures) and losses of life associated with reduced lane departure and increased turn signal use, though crash report data may provide some insights.

#### *5.2.1.5 Preliminary National Highway Traffic Safety Administration (NHTSA) Vehicle to Vehicle (V2V) Communications Research*

**Evaluation Goal**

In August 2014, the National Highway Traffic Safety Administration (NHTSA) published an Advanced Notice of Proposed Rulemaking (ANPRM) and accompanying research report concerning V2V technology and adaptation [60]. This report provides NHTSA's preliminary research findings and interpretations in several areas vital to the V2V effort. These areas include NHTSA's regulatory authority concerning V2V technology, the feasibility of the proposed technology and system, and privacy and security considerations that will impact public acceptance of the program. The report additionally provides preliminary estimates of benefits and costs for two V2V arterial safety applications: Intersection Movement Assist (IMA) and Left Turn Assist (LTA).

**Hypotheses**

V2V and other driver-oriented crash avoidance applications will provide extensive benefits through the mitigation of fatalities, injuries, and economic loss.

**Performance Measures**

- LTA
- Left turn across path/opposite direction crashes
- IMA
- Junction-crossing crashes
- False positives
- Driver acceptance

**Evaluation Approach**

NHTSA's multi-pronged methodology included an evaluation of the Safety Pilot conducted in Ann Arbor, Michigan (which included a pilot deployment and driver surveys), research concerning regulatory authority, liability, privacy, and other issues, readiness of available technology and considerations for future technology, an analysis of the need and impact of V2V safety applications, and a preliminary effectiveness and benefit-cost analysis of the IMA and LTA safety applications.

**Data**

Data outputs from the BCA include crashes avoided and fatalities and Maximum Abbreviated Injury Scale (MAIS) 1-5 injuries prevented via introduction of the two applications. Inputs to the calculation include crash avoidance, crashworthiness, and application effectiveness.

**Key Findings**

The preliminary benefits calculated for the IMA and LTA applications vary depending on the calculation assumption and the aggressiveness of V2V technology adaptation. Regardless, the analysis predicts that full implementation of these two applications will annually prevent 25,000 to 592,000 crashes, save 49 to 1,083 lives, avoid 11,000 to 270,000 MAIS 1-5 injuries, and reduce the severity of 31,000 to 728,000 property-damage-only crashes. These accrued benefits compare to projected costs of approximately $350 in V2V technology costs per vehicle in 2020 (in addition to small price increases from the security management system and increased fuel usage due to increased vehicle weight) as well as a total V2V system annual cost range of between $1.1 billion and a theoretical maximum of $6.4 billion per year, decreasing gradually to a theoretical maximum of $4.6 billion in the years following 2024. Overall, despite the lukewarm survey responses gathered during the Safety Pilot survey effort, the results of this model deployment and other efforts lead the authors to hypothesize that V2V technology can produce noticeable safety benefits, including crash, injury, and fatality reduction.

**Challenges and Issues**

- Benefits estimates dependent on escalating fleet penetration
- Two specific future policy needs
    - High-functioning software update mechanism
    - Regulatory determination concerning jurisdiction over roadside units
- Additional research considerations
    - Development of performance standards for DSRC and safety applications
    - Establishment of device certification procedures
    - Options to mitigate communication congestion
    - Ramifications of shared radio spectrums
    - Consumer acceptance/enthusiasm
    - Distribution of liability between drivers, automobile and device manufacturers, and government entities

#### *5.2.1.6 Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis*

**Evaluation Goal**

The VII Initiative Benefit Cost Analysis report [61], published in 2008, is part of an effort by a public-private partnership consisting of the ITS JPO, state and local agencies, and private entities including automobile and telecommunications manufacturers to support the long-term growth and integration of vehicular and infrastructure communications. This benefit-cost analysis (BCA) aims to quantify the long-term benefits and costs of this integration effort, with a more immediate goal of proving expected safety and mobility benefits for the purposes of program advancement.

**Hypotheses**

The VII effort supported by this initiative will result in substantial safety and mobility benefits through a nationwide system of communication between vehicles and roadside infrastructure.

**Performance Measures**

- Value of travel time
- Value of crashes avoided
- Net savings and costs

**Evaluation Approach**

The study team first proceeded to develop a deployment schedule and scenario for the VII effort. The scenario assumes a total (100 percent) share of OBE availability on newly-sold automobiles by 2015. The calculations assumed the eventual fleet exit of existing vehicles without installed OBE. This fleet phase-in predicts an OBE-equipped fleet share surpassing 50 percent by 2020, 90 percent by the early 2030s, and a total share by the late 2040s. The model assumes a five year buildout of roadside equipment to be completed by 2015 and functional application availability by 2011. Cost inputs were then inserted into the model. For benefits, the study team developed the following standardized methodology to estimate safety impacts:

- Use application description to determine crash scenarios
- Review crash databases to quantify yearly relevant crashes for each application
- Develop an “efficacy” estimate (the percentage of crashes that an application may reasonably be expected to prevent)
- Multiply the relevant crash figure by the efficacy estimate to determine number of crashes prevented
- Delineate crashes based on severity of the avoided crashes, which yields avoided fatalities and injuries
- Project these impacts for each year in the theorized schedule, with additional adjustments for factors such as declining crash prevalence
- Translate into monetary terms using statistical value of life and injuries, convert to present terms by applying a discount rate, and summate

**Data**

BCA data inputs include VMT, fleet composition and sales, market penetration assumptions, OBE costs (including installation and maintenance), and roadway infrastructure costs (capital, maintenance, etc.).

**Key Findings**

The expected benefit from application deployment over the 40-year evaluation period is calculated as $44.2 billion compared to $27.3 billion of capital, equipment, and operations and maintenance costs, resulting in a net benefit of $16.9 billion and a benefit/cost ratio of 1.6. All calculations utilized current 2008 dollars. Approximately 95 percent of the calculated benefit results from safety impacts.

**Challenges and Issues**

- Ambitious assumption of 100 percent OBE availability on new automobiles by 2015
- The BCA effort did not quantify safety benefits for four applications: ramp metering, traffic signal timing, winter maintenance, and traveler information
- The calculations may be conservative in some aspects
    - Future enhancement of applications and development of new applications
    - Safety benefit of unreported crashes
    - Value of emissions reductions through mitigation of accident-caused congestion
    - Acceleration of benefits through aftermarket OBE and older vehicle model retrofitting
    - Incorporation of transit and other public vehicles

#### *5.2.1.7 Applications for the Environment: Real-time Information Synthesis (AERIS) – Modeling of the Operational Scenarios*

The objective of the US DOT'S AERIS Program is to generate and acquire environmentally relevant real-time transportation data that supports and facilitates 'green' transportation choices. Working in partnership with the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications research efforts, the program has developed five Operational Scenarios or bundles of connected vehicle applications, each with a different approach to reducing fuel consumption and the resulting emissions. The five Operational Scenarios being investigated include: Eco-Signal Operations, Eco-Lanes, Low Emissions Zones, Eco-Traveler Information, and Eco-Integrated Corridor Management. Three high priority Operational Scenarios - Eco-Signal Operations, Eco-Lanes, and Low Emissions Zones – were then selected for detailed modeling and analysis.

##### 5.2.1.7.1 AERIS Eco-Signals Operations – El Camino Real

**Evaluation Goal**

This analysis assessed the environmental benefits of the Eco-Signal Operations applications [62]. For this task, a simulation and modeling of the applications was conducted in 2013 using a 27-intersection, 6.5 mile segment of the El Camino Real in Northern California that connects Palo Alto and Mountain View. Following the individual modeling of the applications, the applications were combined to function simultaneously within the same modeling environment to assess their compatibility.

Each of the modeled Eco-Signal Operations applications is described below:

- **Eco-Approach and Departure at Signalized Intersections-** Focuses on encouraging "green" approaches to signalized intersections by providing speed advice to drivers as their vehicles are approaching and departing signalized intersections.
- **Eco-Traffic Signal Timing**- Involves dynamically adjusting signal phase and timing plans based on the speed of vehicles approaching an intersection and vehicle emissions characteristics to optimize signal timing strategies.

- **Eco-Traffic Signal Priority**- Aims to reduce emissions by granting signal priority to selected transit and freight vehicles by extending the current green time or truncating the red time of the phase immediately preceding the green phase favorable to the transit route.
- **Connected Eco-Driving-** Focuses on providing real-time driving advice (e.g., recommended driving speeds, optimal acceleration, optimal deceleration) to drivers based on prevailing traffic conditions and interactions with nearby vehicles.

Figure 5-12 shows the location of the Northern California corridor chosen for the analysis and modeling of the Eco-Signal Operations applications.

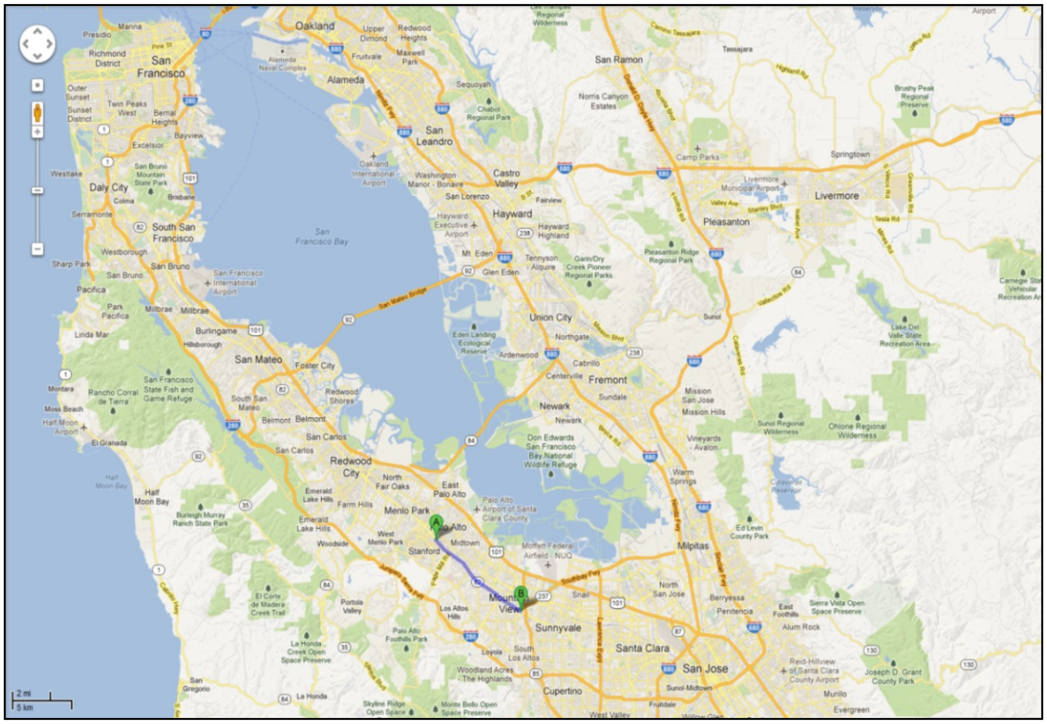


**Figure 5-12: 27-Intersection, 6.5 mile segment of El Camino Real (Source: U.S. DOT, Eco-Signal Operations Modeling Report, 2014, [62])**

Figure 5-13 shows the intersection spacing along the corridor (varied from 650 to 1,600 feet).

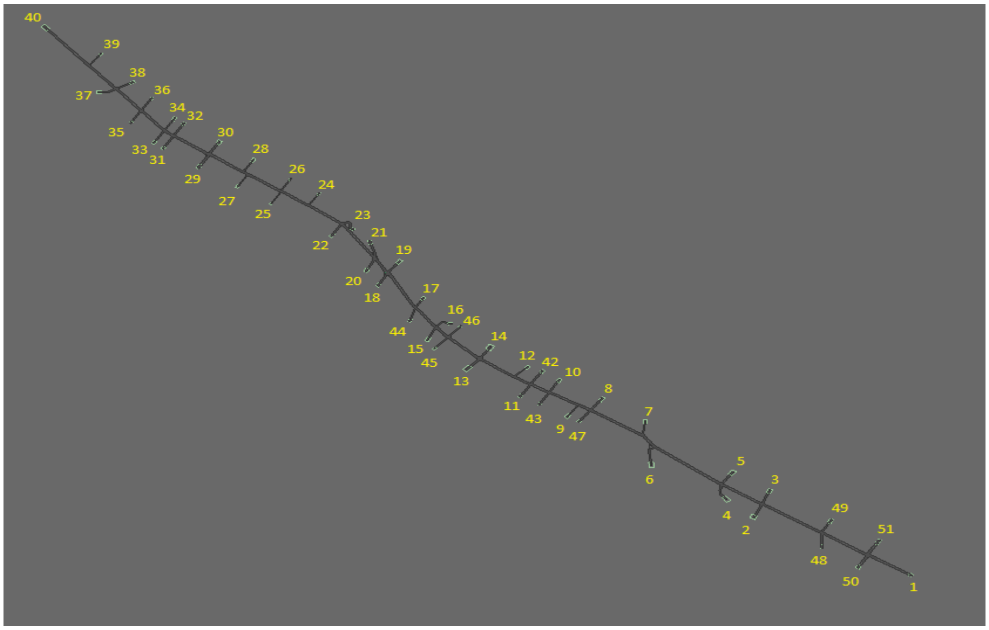


**Figure 5-13: El Camino Real Corridor in Paramics Traffic Simulation Model (*Source: U.S. DOT, Eco-Signals Operations Modeling Report, 2014, [62]*)**

### Hypotheses

- Eco-Approach and Departure at Signalized Intersections
  - 3 percent to 4 percent emissions reductions and lowered fuel consumption will be achieved under partial connected vehicle penetration and 6 percent to 8 percent under full connected vehicle penetration.
- Eco-Traffic Signal Timing
  - 2 percent to 3 percent emissions reductions and lowered fuel consumption will be achieved under partial connected vehicle penetration and 4 percent to 6 percent under full connected vehicle penetration.
- Eco-Traffic Signal Priority
  - 1 percent to 2 percent emissions reductions and lowered fuel consumption will be achieved under partial connected vehicle penetration and 2 percent to 4 percent under full connected vehicle penetration.
- Connected Eco-Driving
  - 10 percent to 15 percent emissions reductions and lowered fuel consumption will be achieved under partial connected vehicle penetration and 15 percent to 20 percent under full connected vehicle penetration.
- Combined Applications
  - 15 percent to 20 percent emissions reductions and lowered fuel consumption will be achieved under partial connected vehicle penetration and 20 percent to 25 percent under full connected vehicle penetration.

### Performance Measures

Environmental measures considered in the analysis include:

- Fuel consumption
- Emissions
  - Carbon dioxide (CO2)
  - Particulate matter: PM-10
  - Particulate matter: PM-2.5
  - Nitrogen oxides (NOx)
  - Volatile organic compounds
  - Hydrocarbons (HC)
  - Carbon monoxide (CO)

Mobility measures considered in the analysis include:

- Mainline corridor travel time
- Delay

**Evaluation Approach**

The Paramics microsimulation tool was used to simulate and analyze the impacts of each of the applications [63]. The identified network (i.e., links, nodes, and their characteristics) and traffic control devices, such as signals, were coded into the microsimulation tool. Algorithms tailored to each individual application were implemented. A variety of scenarios were modeled to characterize the detailed behavior of the applications under different conditions, such as the varying vehicle demand on the network, the percentage of trucks, different communication ranges and delay, fleet mix, and most importantly the connected vehicle OBE (onboard equipment) penetration rates (which varied from 20% to 100%). Results were then compared with a baseline model that contained no connected vehicle application deployments.

**Data**

The model was calibrated against field data of roadway geometry, traffic origin-destination (OD) matrix, vehicle mix, and traffic signal settings for the year 2005. Vehicle demands and their OD patterns were calibrated to a typical weekday in summer 2005. The OD trip tables were used to create volume inputs for the microsimulation. The vehicle fleet mix was derived from vehicle registration databases or obtained directly from available field data.

**Key Findings**

The following findings were presented in the Eco-Signal Operations Modeling Report [62]:

Eco-Approach and Departure at Signalized Intersections

- 2 percent to 8 percent energy savings were observed, with greater benefits resulting from increased connected vehicle penetration rates.
- Less effective when corridor was congested.
- Benefits increased with longer communication distance because of better trajectory planning (Distances of 0 m to 120 m were tested).
- Greater benefits resulted for the corridor on which traffic signals were less coordinated.

Eco-Traffic Signal Timing

- 1 percent to 5.5 percent emissions reductions were observed, with greater benefits resulting from increased connected vehicle penetration rates.
- Effective at most levels of congestion, but improvements dropped off as the system reached saturation.
- The effect of communication distance was not relevant for this application.
- Resulting Eco-Optimized Signal Timing plans have significantly shorter cycle lengths than traditionally optimized corridor timing plans.

Eco-Traffic Signal Priority

- 1 percent to 4 percent fuel savings for freight vehicles and 2 percent to 4 percent fuel savings for transit vehicles were observed, with greater benefits resulting from increased connected vehicle penetration rates.
- Most effective in low congestion scenarios.
- Longer communication distances did not increase the benefits, because the approach trajectory can be calculated reliably at any distance from the signal.
- Similar fuel savings were achieved for non-connected vehicles as well as passenger vehicles that shared additional green time.

Connected Eco-Driving

- 1 percent to 18 percent emissions reductions, and 1 percent to 6 percent fuel savings were observed for all vehicles, with greater benefits resulting from increased connected vehicle penetration rates.
- Most effective in low-congestion scenarios.
- Had no effect on energy consumption, but emission reductions increased with increasing penetration rate.
- The effect of communication distance was not assessed.
- Works best when intersection distances are longer than the range of DSRC communication systems.

Combined Applications

- 10 percent improvement in fuel consumption/$CO_2$ emissions, and 15 percent to 25 percent improvement in emissions of other resultant pollutants were observed, with greater benefits resulting from increased connected vehicle penetration rates.
- The individual results were not additive but no one application significantly hindered the other applications.
- Passenger vehicle benefits plateaued at about a 65 percent OBE penetration rate.

**Challenges/Issues**

- In saturated flow conditions, the Eco-Approach and Departure application cannot provide accurate speed advice or the advice cannot be properly followed, resulting in an overall “disbenefit” to the system.

- Modeling results were designed for fixed-time signals. Under actuated signal control scenarios, it is much more difficult to estimate SPaT (Signal Phasing and Timing) information (e.g., the remaining time of the current phase), which might result in lower environmental benefits than expected.

### 5.2.1.7.2 AERIS Eco-Lanes – California SR-91

**Evaluation Goal**

The analysis of the Eco-Lanes Operational Scenario assessed the environmental benefits of connected vehicle applications built around dedicated “eco-lanes” [64]. For this task, a simulation and modeling of the applications was conducted in 2014 on State Route 91 Eastbound (SR-91 E) in Southern California between the Orange County Line and Tyler Street in Riverside, California. Due to limitations in budget and time, only two of the seven applications bundled under the Eco-Lanes Operational Scenario were modeled. Following the individual modeling of the two applications, they were combined to function simultaneously within the same modeling environment to assess their compatibility. The two modeled applications are briefly described below:

- **Eco-Speed Harmonization (ESH):** Involves dynamically changing speed limits on links that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect flow. The ESH application is similar to the current VSL application; however, the speed recommendations specifically target the reduction of emissions and fuel consumption along the roadway.
- **Eco-Cooperative Adaptive Cruise Control (Eco-CACC):** Focuses on subject vehicles automatically adjusting their speeds based on speed and acceleration data of preceding vehicles to fit the most environmentally efficient trajectory. In a sense, Eco-CACC creates loosely coupled platoons, where two or more vehicles travel with small gaps, which could reduce aerodynamic drag, depending on the following distances.

Figure 5-14 shows the location of the Southern California freeway corridor chosen for the analysis and modeling of the Eco-Lane Eco-Speed Harmonization and Eco-CACC applications.

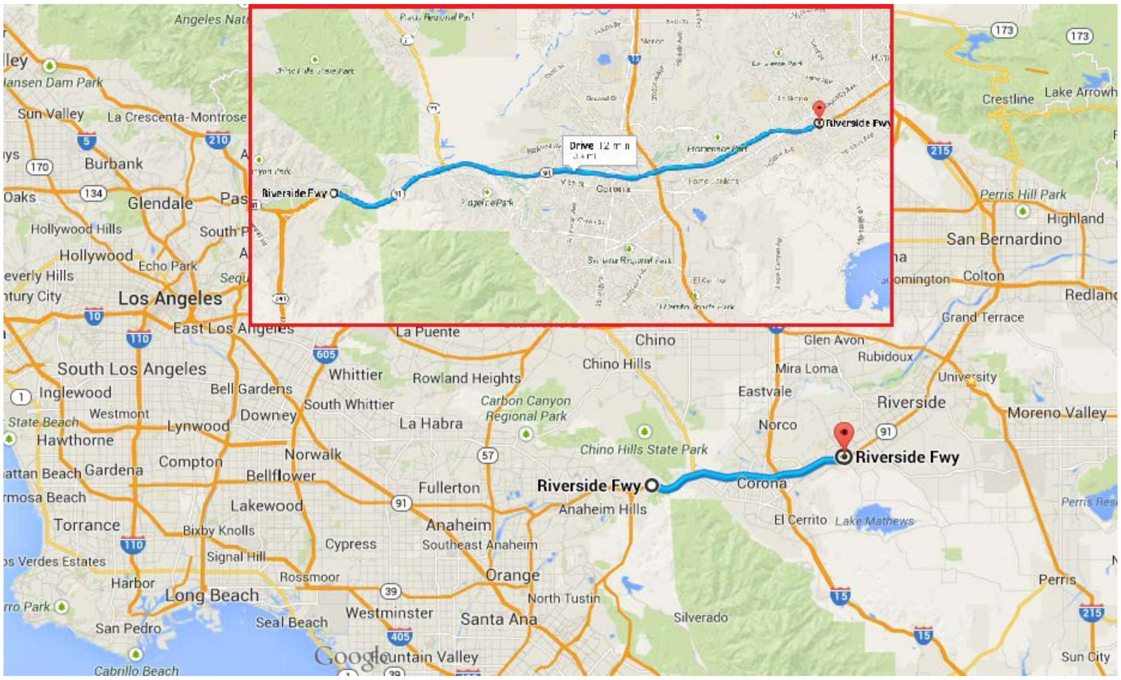


**Figure 5-14: State Route 91 Eastbound (SR-91 E) in Southern California between the Orange County Line and Tyler Street in Riverside, California (*Source: U.S. DOT, Eco-Lanes Operational Scenario Modeling Report, 2014, [64]*)**

**Hypotheses**

Eco-Speed Harmonization (ESH)

- A reduction of energy consumption and pollutant emissions by as much as 5 percent will result with a 100-percent penetration rate of OBE.
- The occurrence of (discretionary) lane change maneuvers will decrease.
- Energy savings will decrease under partial penetration rate of CV technology. However, the mobility impact may not follow the same linear trend.

Eco-CACC- based on 100-percent penetration rate of OBE, a single dedicated lane for platoons, and a platoon clearance (inter-vehicle spacing) of 15 meters:

- Platoons will provide as much as 20 percent reduced travel time and 10 percent reduced energy consumption.
- At low traffic volumes in the initial platoon maneuver (25,000 vehicles per hour), a penalty of less than 5 percent in energy and emissions may be present relative to a non-platoon baseline. In contrast, at higher traffic volumes (up to 37,000 vehicles per hour), vehicles in platoons may experience energy consumption reductions of as much as 20 percent.
- Vehicles not participating in platoons will receive moderate indirect benefits of as much as 10 percent energy savings.

Combined Applications

- The combination of ESH with Eco-CACC will provide 0 percent to 5 percent additional energy benefits relative to the benefits of just Eco-CACC.
- The mobility benefits are expected to fall within the range of plus or minus 5 percent savings added to the independent Eco-CACC results.

**Performance Measures**

Environmental measures considered in the analysis included:

- Fuel consumption
- Emissions
  - Carbon dioxide (CO2)
  - Particulate matter: PM-10
  - Particulate matter: PM-2.5
  - Nitrogen oxides (NOx)
  - Volatile organic compounds
  - Hydrocarbons (HC)
  - Carbon monoxide (CO)

Mobility measures considered in the analysis were average travel time.

**Evaluation Approach**

With the Paramics microsimulation tool [63] and the EPA's Motor Vehicle Emissions Simulator (MOVES, [65]) emissions estimation tool, individual vehicle movements were modeled per the scenario implemented, allowing for fuel consumption and emissions of vehicles to be accurately estimated. A variety of sensitivity scenarios were modeled, that included varying parameters such as vehicle demand of the network, CV OBE penetration rate, triggering distance for the Eco-CACC application, and intra-platoon clearance for the Eco-CACC application.

A baseline model was developed from the SR-91 E model for comparing the resultant emissions. The baseline model used overall travel time statistics and assumed that there was no application deployment (i.e., CV penetration rate was zero).

**Data**

The SR-91 E model network was previously coded in Paramics for research performed by the University of California at Riverside to evaluate the impacts of HOV lane configuration on system-wide fuel consumption and pollutant emissions [66]. The model in this evaluation cites data from that study, where traffic demands, vehicle mix, origin-destination (OD) patterns, and driver behavior in the model were calibrated to field data collected on a typical weekday in the summer of 2006.

**Key Findings**

The following findings were presented in the Eco-Lanes Modeling Report [64]:

Eco-Speed Harmonization (ESH)

- At a set traffic volume of 25,000 vehicles per hour, varying technology penetration rates from 5 percent to 100 percent led to an increase in savings in energy consumption from 0.1 percent to 4.4 percent.
- The most significant benefits in terms of energy savings and emissions reduction were obtained when the traffic was heavily congested.
- Assuming a 100-percent OBE penetration rate, a traffic volume of 25,000 vehicles per hour led to an average travel time reduction of -1.7 percent (a disbenefit) while a traffic volume of 37,000 vehicles per hour led to an average travel time reduction of 1.3 percent.
- The benefits in mobility were more variable across different technology penetration rates (especially under heavily congested traffic conditions).

Eco-Connected Adaptive Cruise Control (Eco-CACC)

- With a 100-percent OBE penetration rate and a vehicle clearance of 5 meters, varying traffic volume between 25,000 vehicles per hour and 37,000 vehicles per hour resulted in reduced travel times of 0 percent to 42 percent and reduced energy consumption of 0 percent to 19 percent.
- With a 100-percent OBE penetration rate and a vehicle clearance of 15 meters, varying traffic volume between 25,000 vehicles per hour and 37,000 vehicles per hour resulted in reduced travel times of 0 percent to 24 percent and reduced energy consumption of 0 percent to 13 percent.
- Assuming a 100-percent OBE penetration rate, the dedicated lane was 3 percent to 12 percent more energy efficient than the non-dedicated lanes and 3 percent to 26 percent more energy efficient relative to the average baseline scenario lane.

Combined Applications

- The overall network benefits ranged from 4 percent to 22 percent savings for energy and -1 percent to 33 percent savings for travel time.
- The combination of ESH and Eco-CACC led to a slight penalty in travel time (up to -1.5 percent) and a small benefit in energy (up to 5 percent) relative to just Eco-CACC testing.
- At lower traffic volumes, the general purpose lanes experienced a greater energy savings than the dedicated lane because of the small energy needed for platoon formation. In contrast, at the highest traffic volume, the dedicated lane experienced a greater energy savings than the general purpose lanes because of the increased capacity provided by Eco-CACC.
- Vehicles that chose the dedicated lane received a travel time benefit of more than 10 percent with a slight energy penalty of at most -3 percent relative to vehicles that did not select a dedicated lane.

**Challenges/Issues**

- The ESH algorithm will need to be further enhanced such that it can be more adaptive to different networks and traffic conditions.
- For Eco-CACC, additional testing must be conducted at higher volumes to quantify the difference in capacity between vehicle clearances of 5 meters and 15 meters.
- The inclusion of all lanes as dedicated lanes will necessitate the creation of a merging protocol designed around on-ramps.

### 5.2.1.7.3 AERIS Low Emissions Zones – Greater Phoenix Metropolitan Area

**Evaluation Goal**

The analysis of the Low Emissions Zone Operational Scenario assessed the environmental benefits of geo-fenced cordon areas that deter the access of high-polluting vehicles, known as Low Emissions Zones (LEZ, [67]).

For this evaluation, modeling was performed in 2014 using a regional-scale model of the MAG (Maricopa Area Governments) region in Phoenix, Arizona, an area chosen for its dense retail and residential activity. The LEZ area encompassed 134 zones (about 4.4 percent of all zones). The LEZs created targeted emissions reductions through the use of a monetary incentive to motivate a higher market penetration and use of eco-friendly vehicles (HEV, PHEV, EV) in the context of travel to and from the LEZ areas. The LEZs were tested both with and without an additional enhanced transit (ET) component; this enhanced transit component provided travelers who chose not to use or buy an eco-vehicle an incentive through mode-shift.

**Hypotheses**

The following hypotheses were examined:

- An incentive-based LEZ strategy will result in reductions in emissions in the targeted LEZ sub-area.
- An incentive-only based LEZ strategy will not result in any appreciable change in traffic congestion.
- An incentive-based LEZ strategy may result in induced travel demand in the LEZ caused by new trips from eco-vehicle travelers.
- ET service coupled with an incentive-based LEZ scheme will further amplify the emission benefits associated with a LEZ.
- ET service coupled with an incentive-based LEZ scheme will result in reduced automobile travel demand (in the LEZ sub-area) as a result of mode shifts, despite any increases that result from induced travel demand (among eco-travelers).

**Performance Measures**

Key measures that were used to test the hypotheses include:

- Emissions
  - Carbon Dioxide ($CO_2$),
  - Nitrous Oxide (NOx)
  - Carbon Monoxide (CO)
  - Hydrocarbons (HC)
- Market penetration of eco-friendly vehicles
- Transit mode-share
- Vehicle Miles Traveled

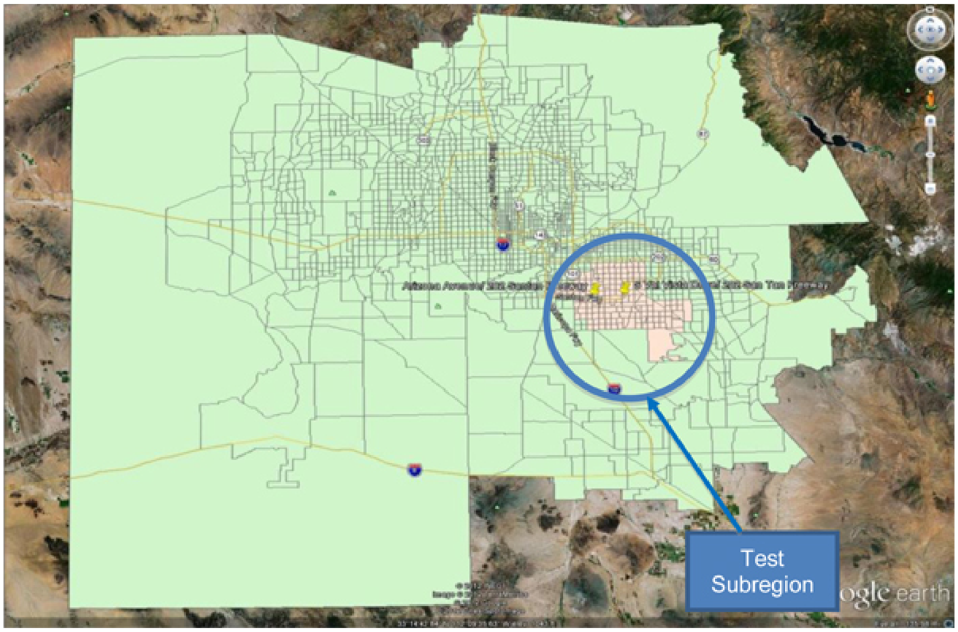


**Figure 5-15: Map of Maricopa County Model Region Showing TAZs and Southeast Three-City Test Sub-Region (*Source: U.S. DOT, Low Emissions Zone Modeling Report, 2015, [67]*)**

**Evaluation Approach**

An integrated travel model system was used that coupled the openAMOS activity-based microsimulation travel demand model [68] with the DTALite dynamic traffic assignment model [69] to simulate the behavioral changes that the introduction of LEZ scenarios brought about. The integrated model system was exercised both for a small test sub-region of the Greater Phoenix metropolitan area as well as for the region as a whole.

The scenarios modeled in this study can be described as follows:

- Travelers were offered an incentive equivalent to a monetary benefit on a per-trip basis. The incentive values considered included $0.50 or $1.50 per trip (low and high incentive level).
- The incentive was provided only when a traveler entered the LEZ using a low-emission vehicle; no incentive was offered for travelers exiting the zone.
- The monetary incentive was tested both with and without enhanced transit service for the LEZs. Service to and from the LEZs under enhanced transit doubled the frequency of transit and reduced the fare by 50-percent.
- Results were then compared against a baseline scenario that assumed an incentive equal to zero.

**Data**

Maricopa Area Governments (MAG) provided network files, travel data, traffic volume data, and travel time and cost matrices by time of day period. These files served as the foundation for building the microsimulation model systems of dynamic travel demand and route choice in response to LEZ scenarios.

In addition, a 2006 BenDor and Ford study provided information for the elasticity-based approach that was used to determine the penetration of eco-vehicles in the market in response to the LEZ incentive [70].

**Key Findings**

The following findings were presented in the AERIS Low Emissions Zones Modeling Report [70]:

- Energy and emissions reductions of 2 percent to 5 percent were realized for the entire region under consideration (including LEZs and regular zones). The lower end was achieved in the absence of ET service, while the higher end was achieved in the presence of ET service for the LEZs.
- When ET service was available in LEZs, the energy and emissions reductions for the LEZs were amplified substantially and found to be in the range of 15 percent to 18 percent.
- Regular zones without the ET service also experienced 3-4 percent reductions in emissions, thus presenting substantial secondary benefits that go well beyond the confines of the LEZs.
- The market penetration of eco-friendly vehicles may reach about 5 percent in the short term (5–7-year timeframe); this level of market penetration is sensitive to the incentive level and the maximum allowable lifetime benefit.

**Challenge/Issues**

- Computational difficulty associated with running an integrated travel model system for an entire region the size of Greater Phoenix forced the project team to re-direct their focus to a smaller sub-region.
- Due to complications associated with defining or calculating the monetary equivalent of a non-monetary reward-based scheme, only monetary incentives were considered for this simulation.
- This study did not consider the financial viability and costs associated with implementing the LEZ incentive scheme.

#### *5.2.1.8 Dynamic Mobility Applications (DMA)*

##### 5.2.1.8.1 Intelligent Network Flow Optimization (INFLO)

**Evaluation Goal**

This evaluation involved the assessment of two applications from the Dynamic Mobility Applications Program's Intelligent Network Flow Optimization (INFLO) application bundle, whose goal is to optimize traffic flow through the use of connected vehicle-drawn data. The two assessed applications are described below:

Dynamic Speed Harmonization (SPD-HARM) –adjusts and coordinates maximum appropriate vehicle speeds in response to downstream congestion, incidents, and weather or road conditions to maximize traffic throughput and reduce crashes.

Queue Warning (Q-WARN)- provides a vehicle operator with sufficient warning of an impending queue backup in order to brake safely, change lanes, or modify the route such that secondary collisions can be minimized.

A two-pronged approach was used for the assessment of the SPD-HARM and Q-WARN applications:

- An extensive analysis of a Prototype was performed using a VISSIM simulation model for an 8.5-mile segment of US 101 freeway in San Mateo, CA.
- In January 2015, an evaluation of a small-scale demonstration was conducted on a 23-mile stretch of the I-5 freeway in Seattle, WA.

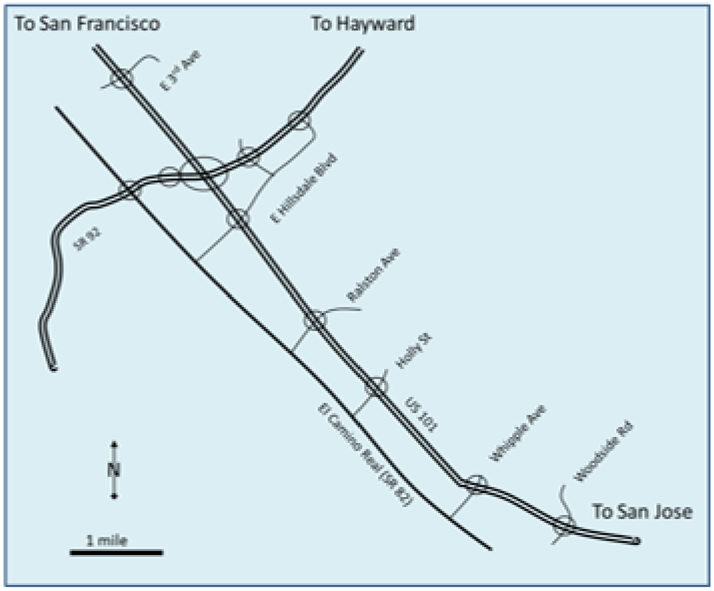


**Figure 5-16: Map of the selected San Mateo, California, US 101 freeway test site. (*Source: U.S. DOT, Impacts Assessment of Dynamic Speed Harmonization with Queue Warning, 2015, [71]*)**

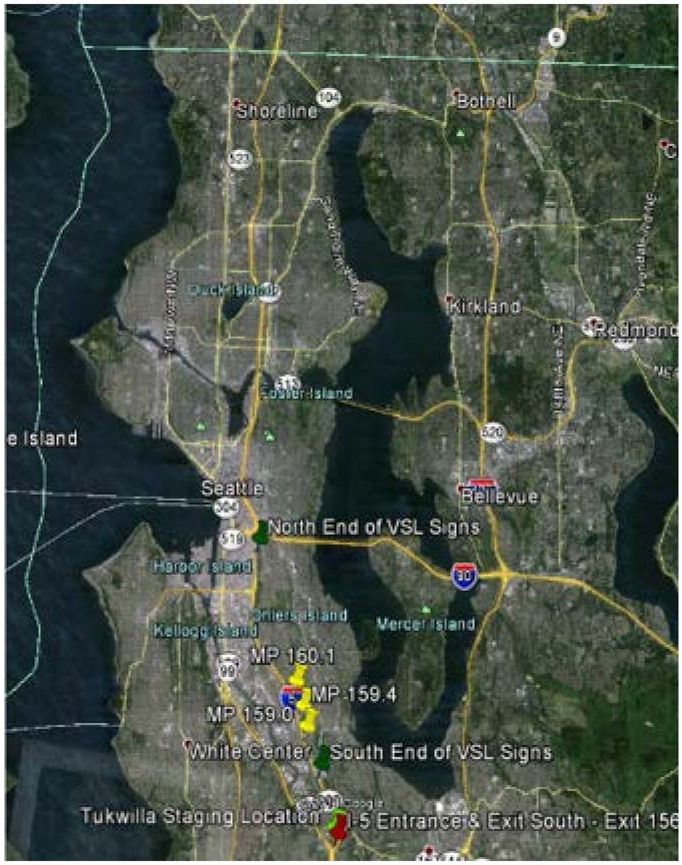


**Figure 5-17: Map of the Seattle demonstration area. (*Source: U.S. DOT, INFLO Webinar, 2015, [72]*)**

**Hypotheses**

The core hypothesis being examined:

- There are some operational conditions under which SPD-HARM and Q-WARN are most effective.

Hypotheses involving further examination and extrapolation of the data:

- Nomadic devices and the facilities may need to be DSRC capable under certain conditions.
- The performance of the prototype will improve as more drivers are connected (market penetration).
- Varying market penetration overtime will result in different benefits in the near, mid, and long-term (with a high market penetration rate being more effective than a low market penetration rate).
- Market penetration, communications loss, and compliance rate are all tied together into the estimation of the overall driver response to V2X guidance.
- Communication errors, losses, and latency all will reduce the effectiveness of SPD-HARM and Q-WARN.

- Roadside equipment (RSE) and cell phone coverage each have their unique benefits for SPD-HARM and Q-WARN, which may vary under certain conditions.
- Existing sensors may provide benefits to SPD-HARM and Q-WARN implementation.
- V2X increases the effectiveness of SPD-HARM and Q-WARN when compared to an RSE only installation.

**Performance Measures**

Key performance measures include:

- Shockwaves: number of shockwaves formed, length (duration), propagation speed
- Queues: Length and Duration (Vehicle-Seconds in Queue per vehicle)
- Throughput (Vehicle-Miles Traveled)
- Speed variance (lane changes/vehicle, stops/vehicle)
- Average travel time (Vehicle Hours Traveled per vehicle)
- Reliability measure: Planning time index ($95^{th}$ Percentile Travel Time Index)

**Evaluation Approach**

Simulation of the Prototype

A previously calibrated VISSIM microsimulation model of the 8.5-mile segment of US-101 was used for a "before and after" analysis of the applications. Modeling was done for six operational scenarios for each of the four different levels of connected vehicle response rates: 0-percent (baseline), 10-percent, 25-percent, and 50-percent (a maximum of 50-percent was used with the implicit assumption that the response rate is the market penetration rate depreciated for communication loss and driver compliance effects.) The six scenarios modeled combined a flat median traffic demand level, three possible severity levels of incidents (none, 1 lane closed – 30 min, 1 lane closed – 60 min) and two possible weather types (dry pavement, wet pavement) for the corridor. Simulation runs were averaged for each scenario and results were then weighted according to their expected frequency over the course of a year to obtain annualized results.

Small-scale Demonstration

Battelle and Texas Transportation Institute (TTI) worked with the Washington State Department of Transportation (WSDOT) to install connected vehicle systems in 21 vehicles. The systems were deployed in a scripted driving scenario traversing both directions of a 23-mile stretch of the I-5 freeway from Tukwila to Edmonds through downtown Seattle during morning rush hour the week of January 12, 2015. During testing, the connected vehicles were first released in pulses (two platoons, 5 minutes or 15 minutes apart) and were next spaced out, with one connected vehicle being released every 30 seconds or so. The system received and processed loop detector and connected vehicle data in real time and delivered both Q-WARN and SPD-HARM messages to drivers when appropriate.

**Data**

The simulation analysis required travel-time, demand, weather, and incident data.

- Travel-time data for 251 non-holiday weekday PM peak periods (2:00 PM - 8:00 PM) for the year 2012 were obtained from the Caltrans PeMS (Performance Measurement System) database for nine miles of US 101.
- Demand data in the form of vehicle-miles traveled (VMT) was downloaded from the PeMS database for the subject freeway study section and directions for 2012.
- Twenty-four hour weather data for nearby San Francisco International airport from 2012 was extracted from the University of Utah on-line database [76].
- Incident logs from the California Highway Patrol (CHP) computer-aided dispatch (CAD) log were obtained from the PeMS database for the year 2012; collision data were obtained from the Caltrans accident reporting system (TASAS) for the latest available year, 2010.

**Key Findings**

Conclusions from the simulation of the Prototype in San Mateo, CA: (findings are exclusively for SPD-HARM)

- The magnitudes of the speed drops (shockwaves) between vehicles was significantly reduced, even at the 10-percent market penetration level.
- Average speeds on freeways were reduced by up to 20-percent, with the greatest impact occurring at the 50-percent connected vehicle level.
- Under severe-congestion conditions (such as during lane-closure incidents), reductions in speed still occurred with the Prototype, but they were less significant than for less-severe conditions.
- There was relatively little effect on vehicle stops.
- There was an increase in the amount of lane changing on the freeway.

Conclusions from the small-scale demonstration in Seattle, WA: (findings are for both SPD-HARM and Q-WARN)

- In general, the cycle of capturing field data, transmitting it to the database, processing it, and delivering messages back to drivers took less than 10 seconds, confirming that drivers can be expected to receive queue warning messages approximately a mile in advance of the back of the queue
- Q-WARN was able to detect the back of queues up to 3 minutes sooner and could pinpoint their geographic location more precisely (0.5 to 1.5 miles farther upstream) than the road loop detectors.
- Connected vehicles capture speeds at smaller intervals to provide more-precise estimates of vehicle speeds in the queue than the infrastructure-based sensors (0.1 mile intervals vs. 0.5 mile intervals)
- Market penetration may influence the ability of the prototype to quickly spot and accurately identify the locations of the backs of queues.

**Challenges/Issues**

- Q-WARN effects could not be explicitly modeled in the microsimulation environment as there was–and still is–a lack of information or behavioral theory regarding how drivers would respond to advance notice of queues. In addition, the small-scale demo was not of

a magnitude to permit isolation of the Q-WARN effects from the SPD-HARM effects on traffic operations.
- Microsimulation is not currently able to support the prediction of crash frequencies as a function of changes in speed distributions caused by SPD-HARM or changes in demand caused by Q-WARN.
- Institutional constraints (asking test drivers to obey SPD-HARM speeds rather than WSDOT Variable Speed Limit speeds) prevented testing of SPD-HARM compliance rates at the small-scale demonstration site.
- Testing of different road detector densities was not feasible at the small-scale demonstration site.

#### 5.2.1.8.2 Multi-Modal Intelligent Traffic Signal Systems (MMITSS)

**Evaluation Goal**

This evaluation set out to assess the mobility benefits of the MMITSS application bundle that uses advanced communications and data from connected vehicle technology to facilitate efficient travel for various vehicle-types and pedestrians through signalized corridors [73].

The MMITSS bundle is composed of several component applications including:

- Intelligent Traffic Signal System (I-SIG), an overarching system optimization application accommodating signal priority, preemption and pedestrian movements;
- Transit Signal Priority (TSP) and Freight Signal Priority (FSP), two applications that provide signal priority to transit at intersections and along arterial corridors, plus signal priority to freight vehicles along an arterial corridor near a freight facility;
- Mobile Accessible Pedestrian Signal System (PED-SIG), an application that allows for an automated call from the smart phone of a visually impaired pedestrian to the traffic signal, as well as audio cues to safely navigate the crosswalk; and
- Emergency Vehicle Preemption (PREEMPT), an application that provides signal preemption to emergency vehicles, and accommodates multiple emergency requests.

The assessment included two major tasks:

- A prototype was developed and field tested in Anthem, Arizona in spring 2015, and;
- Modeling and simulation was performed on the Anthem, Arizona model using VISSIM microscopic simulation software.

The PED-SIG and PREEMPT applications were not ready for testing at the time of the project, and were thus left off the implemented operational scenarios for both the field testing and the simulation.

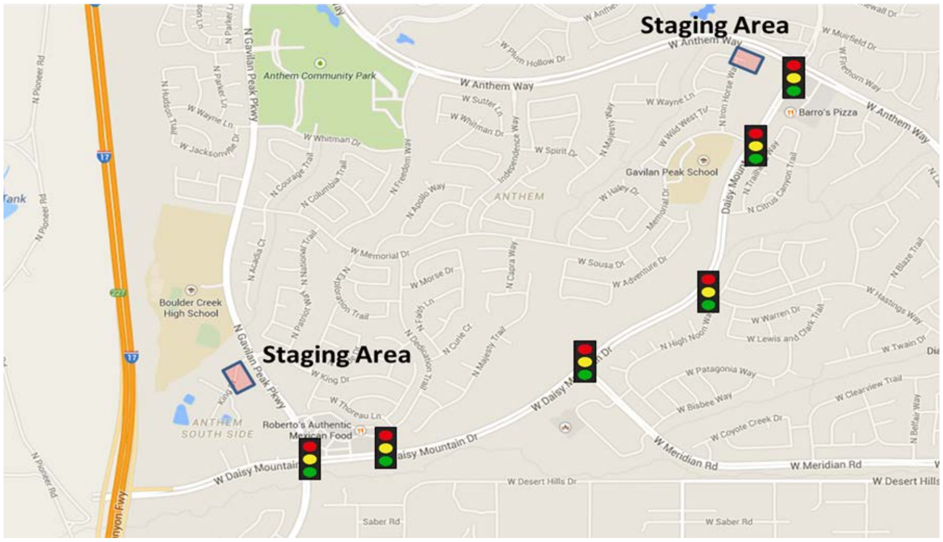


**Figure 5-18: Map of the connected vehicle test bed in Anthem, Arizona (*Source: U.S. DOT, MMITSS Impact Assessment, 2015, [73]*)**

### Hypotheses

- MMITSS I-SIG, TSP, FSP, and TSP/FSP bundle applications can effectively improve vehicle travel time, delay, and travel time reliability for CV-equipped passenger cars, trucks, and transit vehicles on the test facility.
- The system may also produce negative network-wide impacts.

### Performance Measures

Top-priority performance measures for testing:

- Travel times
- Delay times
- Queue lengths
- Average speed
- Number of stops

### Evaluation Approach

Prototype field tests were recreated in the simulation environment. The simulation output was compared with data from the field tests, to properly calibrate the models. The simulation environment was customized to match the traffic signal controller interface, communications environment, and priority algorithms. Major simulation variables included Throughput Volumes, Market Penetration of Connected Vehicles, and Traffic Composition. The study then identified the most beneficial operational conditions for each scenario, through a combination of simulation variables and traffic demand levels.

**Data**

Simulation network calibration required vehicle inputs based on AM peak hour demand, 7 am to 8 am, at the Anthem Arizona site, using Maricopa (MC) DOT Traffic County Data. Static vehicle routing in VISSIM was based on MCDOT intersection vehicle movement data. Vehicle speed distribution and acceleration data were based field data collected in March 2015. The chosen car-following model was the Wiedemann 74 – Arterial model. Saturation flow rate inputs were based on video data observations. A transit and freight route was defined with EB and WB trips only, and no turning movements.

**Key Findings**

Arizona Field Test Findings:

- FSP effectively reduced the delay of connected trucks and unequipped vehicles by up to 20.9 percent and 26.0 percent, respectively, compared with the base case operations.
- TSP/FSP bundle operations improved connected bus travel times by 8.2 percent and connected truck travel times by 39.7 percent.
- I-SIG marginally improved travel times for both equipped and unequipped vehicles compared with the base case scenarios. However, the study found that I-SIG considerably reduced travel time reliability by up to 56 percent compared with the base case.

Arizona Simulation Findings:

- FSP successfully reduced travel times by up to 20 percent for connected trucks. However, the FSP application also increased system-wide delay due to increased delays on side streets.
- TSP reduced travel times by up to 27.8 percent for connected transit vehicles and by up to 17.5 percent for passenger vehicles.
- Under optimum conditions, I-SIG achieved vehicle delay reductions of 20.6 percent.

**Challenges/Issues**

- Some applications within the MMITSS bundle were not ready for testing within the time period of this project. These included coordinated signal operations, Mobile Accessible Pedestrian Signal System (PED-SIG), Emergency Vehicle Preemption (PREEMPT), and any bundles that would have required these component applications.
- Current BSM specification doesn’t contain Mode information.
- Current SSM (Signal Status Message) doesn’t acknowledge all Signal Request Messages (SRM) – only acknowledges one.

#### 5.2.1.8.3 Response, Emergency Staging and Communications, Uniform Management and Evacuation (R.E.S.C.U.M.E.) ─ RESP-STG and INC-ZONE

**Evaluation Goal**

Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) is a DMA bundle of applications that targets the improvement of traffic safety and mobility during crashes and other emergencies that affect the highway network. This assessment specifically tested the ability of the RESP-STG and INC-ZONE applications within the R.E.S.C.U.M.E bundle, which are each described below:

- Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG) – designed to provide information about the incident scene to emergency responders before their arrival.
- Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE) - an in-vehicle messaging system that provides drivers with merging and speed guidance as they approach an incident zone.

The evaluation included two parts:

- A prototype of the INC-ZONE and RESP-STG applications was exhibited in a small-scale demonstration in Sykesville, Maryland in November 2014.
- Modeling and simulation of the INC-ZONE and RESP-STG applications was performed on an 8.5-mile stretch of the US 101 freeway in San Mateo County in California.

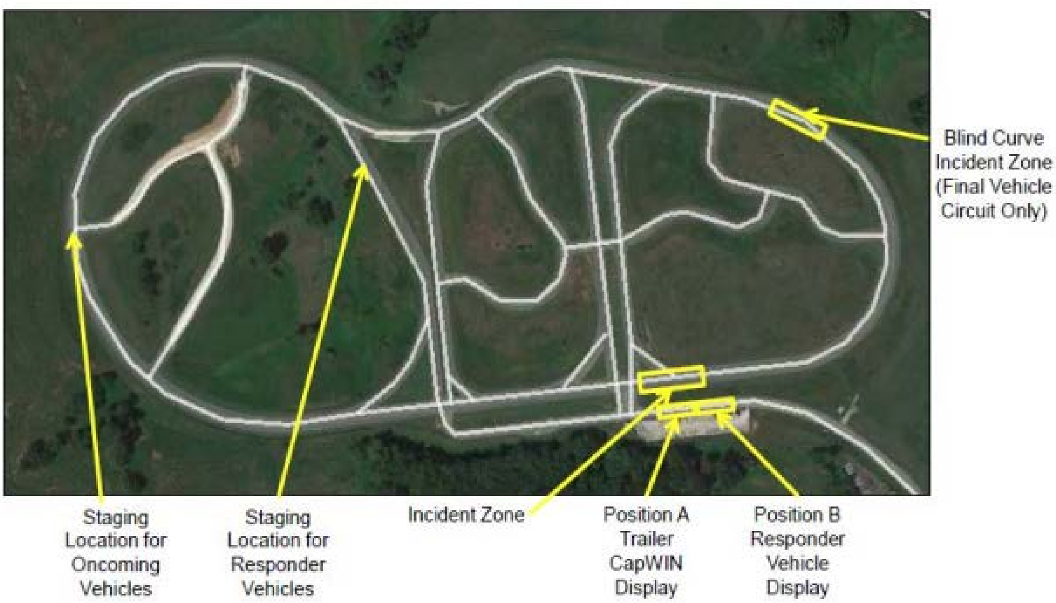


**Figure 5-19: Overview of the R.E.S.C.U.M.E Demonstration Test Track in Sykesville, MD (*Source: US DOT, Impact Assessment of Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE) and Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG), 2015, [74]*)**

**Hypotheses**

- Total response and clearance time will be reduced
- Congestion and delay time will be reduced
- En-route travel times for response vehicles will be improved
- Secondary incidents will be reduced

**Performance Measures**

The following measures, pertaining to mobility and safety with indirect environmental consequences, were used to assess the impacts of the R.E.S.C.U.M.E. applications:

- Average delay
- Average speed
- Section throughput
- Travel Time
- Maximum deceleration
- Average sublink speed
- Average following distance
- Number of stops

**Evaluation Approach**

Prototype Demonstration

For the Sykesville, Maryland demonstration, 12 scenarios were tested to show the functionality of the RESP-STG and INC-ZONE applications. The applications were viewed from three different perspectives– CapWIN perspective (Position A in Figure 19), which represented the platform in which the applications were implemented, responder perspective and prototype oncoming vehicle perspective. Following the demonstration, a qualitative assessment was performed that was based on interviews conducted with the participants from the demonstration.

Modeling and Simulation

For the simulation, 24 scenarios were modeled utilizing various operational conditions: two incident conditions (long, short), two weather conditions (dry, rainy) and 6 levels of CV market penetration rates (0%, 10% 25%, 50%, 75%, 100%). A quantitative assessment of modeling and simulation examined the potential impacts of INC-ZONE and RESP-STG at a microscopic scale around incident zones and at an extrapolated regional level.

**Data**

2012 travel time data was used for simulation model calibration. Demand data was extracted from Caltrans Performance Measurement System (PeMS) database. Incident data from California Highway Patrol Dispatch Data was used to create incidents at the locations that historically had the highest incident rates.

**Key Findings**

Prototype Demonstration Interviews

Overall, participants were very impressed with the effectiveness of the R.E.S.C.U.M.E. system and believed that the technology had the potential to reduce response and clearance times and congestion.

Modeling Results

- For long incident scenarios, the reduction in network delay was between 1 percent and 14 percent, and the increase in average speed was between 1 percent and 8 percent for dry conditions.
- For short incident scenarios, the reduction in network delay was between 1 percent and 7 percent, and the increase in average speed was between 0.25 percent and 3 percent for rainy conditions.
- Reduction in maximum deceleration was found to be between 1 and 89 percent for different operational conditions, with the highest improvement being for the dry conditions with long incident case.

**Challenges/Issues**

- For the demonstration, placing the connected vehicle applications on the responder and oncoming vehicles was a challenge.
- Implementing DSRC messaging between responder and oncoming vehicles to support threat and imminent crash warnings also presented issues.
- A potential improvement area is the implementation of lane-level mapping and an accurate GPS positioning system.

#### 5.2.1.8.4 Response, Emergency Staging and Communications, Uniform Management and Evacuation (R.E.S.C.U.M.E) ─ EVAC

**Evaluation Goal**

Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) is a DMA bundle of applications that targets the improvement of traffic safety and mobility during crashes and other emergencies that affect the highway network. This assessment set out to test the ability of the Emergency Communications for Evacuation (EVAC) application within the DMA bundle on providing travelers information to assist with an evacuation. Potential impacts of EVAC were assessed through the application of a simulation model of the Greater New Orleans region. The simulation of the metropolitan area sought to replicate the travel processes of the Katrina evacuation of August 2005.

**Hypotheses**

- A percentage of evacuees will follow the EVAC recommendations and adjust their behavior accordingly;
- EVAC will enable evacuees to reach destinations faster;
- EVAC will reduce the overall congestion level and delay;
- EVAC will enable evacuees to find hotel accommodations faster;
- EVAC will reduce the number of stops for re-fueling vehicles.

**Performance Measures**

- Vehicle kilometers traveled
- Vehicle hours traveled
- Vehicle hours of delay

- Percentage of time congested
- Travel time differences
- Travel time to lodging facilities
- Unfulfilled fueling demand
- Average wait time

**Evaluation Approach**

Seven simulation scenarios were developed, including a base scenario and six additional strategy scenarios in which EVAC functionality or a combination of functionalities were modeled. The functionalities modeled in scenarios included information on traffic and road conditions, location of available lodging, and location of fuel, food, water, cash machines, and other necessities. The sensitivity of the potential benefit of the EVAC functionality was examined by simulating it under three levels of EVAC market penetration, including 15 percent, 25 percent, and 50 percent.

**Data**

The New Orleans regional evacuation traffic model was calibrated using actual mass evacuation traffic counts from Hurricane Katrina in 2005. The data came from the Louisiana Department of Transportation and Development's (LA DOTD) traffic data collection stations.

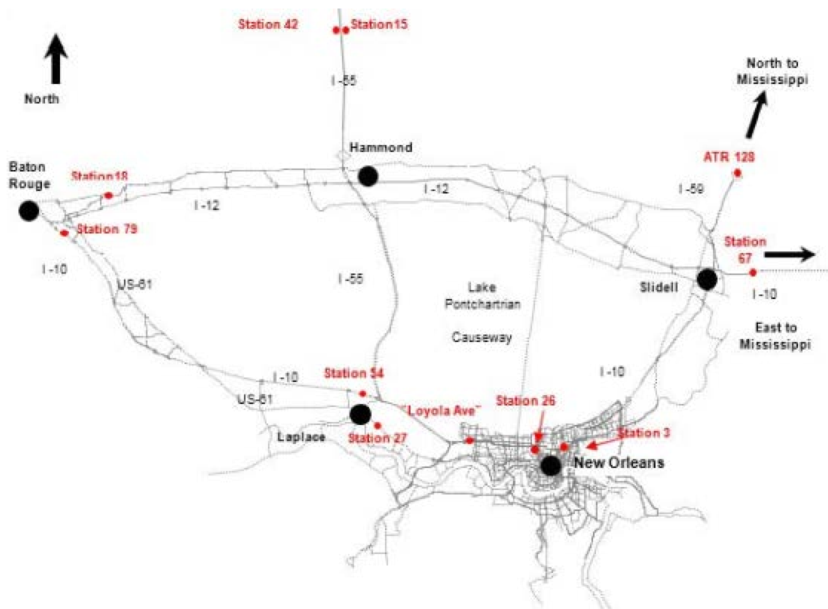


**Figure 5-20: New Orleans Analysis Area and LA DOTD's Traffic Data Collection Stations (*Source: US DOT, Emergency Communications for Evacuation (EVAC) in New Orleans Impact Assessment Report, 2015, [75]*)**

**Key Findings**

- The percentage of time congested decreased by about 20 percent for all penetration rates.

- EVAC reduced the wait time for transit services by over 90 percent for EVAC-equipped evacuees
- At 50 percent penetration, fuel-related breakdowns were reduced by more than 50 percent.
- On average, evacuees seeking lodging experienced a 2-hour travel time benefit.

**Challenges/Issues**

Since the information communications and the behaviors of evacuees upon receipt of information were outside the scope of this study, only the effectiveness of accepting recommendations from EVAC were modeled.

## 5.2.2 Summary of Evaluation Tools and Methods Used in Japan

This section summarizes existing evaluation tools and methods used in Japan to assess performance and benefits of ITS and cooperative systems.

### 5.2.2.1 Traffic Smoother Service

**Evaluation Goal**

The goal of this service was to examine driver behavior upon receipt of “lane-change” or “keep left” messages upstream of congestion by collecting traffic data on expressway sag sections. Drivers' acceptance of the service was evaluated as well. [77]

**Hypotheses**

- Drivers will change lanes upon receipt of information sent via the vehicle device or the road side LED display.
- Drivers will stay in the left lane upon receipt of information sent via the vehicle device or the road side LED display.

**Performance Measures**

- Behavior of vehicles
- Drivers' understanding level of the information

**Evaluation Approach**

The behavior of the vehicles was measured by road side cameras. Drivers' understanding level of the information was evaluated by a questionnaire survey.

**Data**

- Field operational tests were conducted during congested times of day on Saturdays, Sundays, and holidays, from December 2009 to February 2010.
- The treatment group of monitor drivers who received information from the road side LED display consisted of 35 people.

- The treatment group of monitor drivers who received information from the vehicle devices consisted of 39 people.
- Ordinary drivers who answered the questionnaire included a group of 442 people.

**Key Findings**

Monitor drivers who changed lanes using information from the road side LED display were 2 people. Monitor drivers who changed the lane using information from the vehicle device were 6 people. Percentage of lane-changing drivers increased from 6.5% to 9.1% from the service. Percentage of drivers staying in the left lane increased from 76.2% to 82.3% from the service. The effectiveness of the service was verified through the behavior change. Approximately 45% of monitor drivers answered that they could understand the information provided by the road side LED display. Approximately 90% of monitor drivers answered that they could understand the information provided by the vehicle device.

**Challenges and Issues**

Continuous research is needed for practical use of the service. Investigation of new services which collaborate with automotive technology is also needed.

#### 5.2.2.2 Sharp Curves

**Evaluation Goal**

This service uses DSRC-compatible onboard units to provide visual and audio warnings to drivers regarding slow or standing vehicles, or congestion ahead, which are not visible to the driver due to a sharp curve in the roadway (see Figure 5-21).

An FOT was conducted at Sangubashi Curve, on Route 4 (Shinjuku Line) of the Tokyo Metropolitan Expressway, during 2003 to 2008. The system has been operational since 2008. This location experiences frequent congestion. A roadside sensor in the curve section detects congestion, slow, or standing vehicles and transmits the information to vehicles via a roadside unit located approximately 300 meters upstream of the curve.


**Figure 5-21 : Providing information on obstacles ahead at Sangubashi Curve *(Source: MILIM, AHSRA,* Project Report of Advanced Cruise-Assist Highway Systems 2005. *[78])***

**Hypotheses**

Many factors of accidents are related to driver behavior just before the accident, such as error in judgment and a delay of discovery. Providing information on obstacles ahead in advance may reduce accidents.

**Performance Measures**

- Number of accidents
- Curve approaching speed
- Number of sudden deceleration
- Drivers' satisfaction with the service

**Evaluation Approach**

The number of accidents in past fiscal years and that of the field test period at the Metropolitan Expressway No.4 (Shinjuku Line), were compared.

The curve approaching speed and incidence of sudden deceleration were measured by the data of the AHS image processing sensor.

Monitor drivers were recruited from ordinary drivers, and participated in the experiment and questionnaire survey. WEB monitors were also recruited from ordinary drivers.

**Data**

- The number of accidents from March 1st to April 27th in 2003, 2004 and 2005, at the Metropolitan Expressway No.4 (Shinjuku Line).
- The number of monitor drivers was 259.
- The number of respondents of the questionnaires on the WEB was 37.

**Key Findings**

The number of accidents decreased by 44% at the curve of Sangubashi compared to the previous year. Regarding the curve approaching speed, 10% of whole traffic decreased it from over 60 km/h to 50 to 60 km/h. Approximately 4 to 10% of whole traffic decreased their velocity mildly. Approximately 85% of monitor drivers responded that this service was effective in the questionnaire. About 90% of them answered that they wanted this service to be continued.

**Challenges and Issues**

It is necessary that this service be improved for future use, according to the drivers' evaluation. It is also necessary that the service be evaluated continuously by conducting field operational tests at other hazardous curves.

#### 5.2.2.3 Vertical Curve

**Evaluation Goal**

In addition to providing information about obstacles in the roadway that lay beyond a curve, warning information is also provided at sloped off ramps. At the Rinkai-Fukutoshin off-ramp on Route B (Bay Shore Route) of the Tokyo Metropolitan Expressway, there are traffic lights located past the hill crest (vertical curve), so that drivers approaching cannot see vehicles stopped at the traffic lights. The congestion information is transmitted to the ITS Spot-compatible on-board unit by ITS Spot, a DSRC-enabled device installed at the entrance of the off ramp. Visual and audio warnings about congestion are provided to approaching drivers before entering the off-ramp. An FOT was conducted in 2009. An example of a deployment of this application can be seen in Figure 5-22.

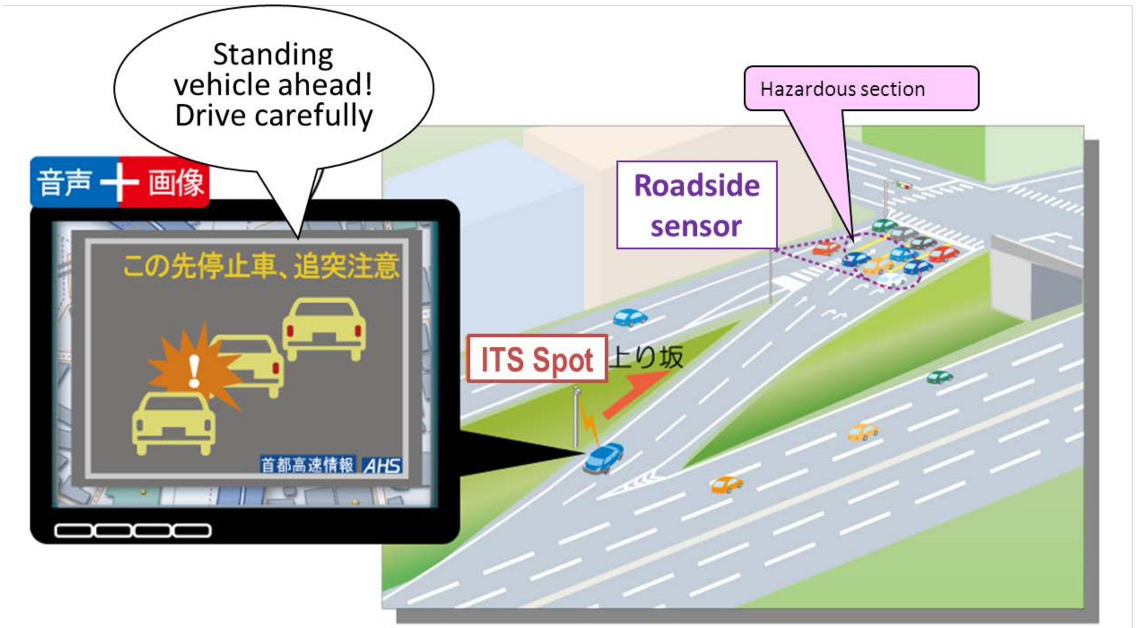


**Figure 5-22: Rinkai-Fukutoshin Inclined Off Ramp Example *(Source: MILIM, AHSRA,* Project Report of Advanced Cruise-Assist Highway Systems 2008. *[79])***

**Performance Measures**

- Vehicle speed when entering sections with poor visibility

**Evaluation Approach**

- Subjects were chosen who never ran the study site.

**Data**

- Vehicle speed was measured at the point where the driver can first start to see the vehicles that stop at the signal.

**Key Findings**

- As a result, it was confirmed that vehicle speed is reduced 3 km/h.
- Services for Providing Information on Obstacles Ahead are effective not only sharp curve such as Sangubashi Curve but also the underpass or the tunnel entrance.

**Challenges and Issues**

- None

#### 5.2.2.4 Merging Assistance

### Evaluation Goal

Complex roadways, where two or more roads merge, are dangerous for drivers. This service provides drivers traveling on the main road with information that warns them about drivers that are about to merge onto the main road (Figure 5-23). By receiving this information, drivers on the main road are able to reduce their stress as other vehicles merge, and drivers on the main road may adjust their speed to provide a gap for merging vehicles. The FOT was conducted at the Higashi-Ikebukuro entrance to Route 5 (Ikebukuro Line) and at Tanimachi Junction, Route C1 (Inner Circular Route) of the Tokyo Metropolitan Expressway in 2007. The system has been operational since 2007.

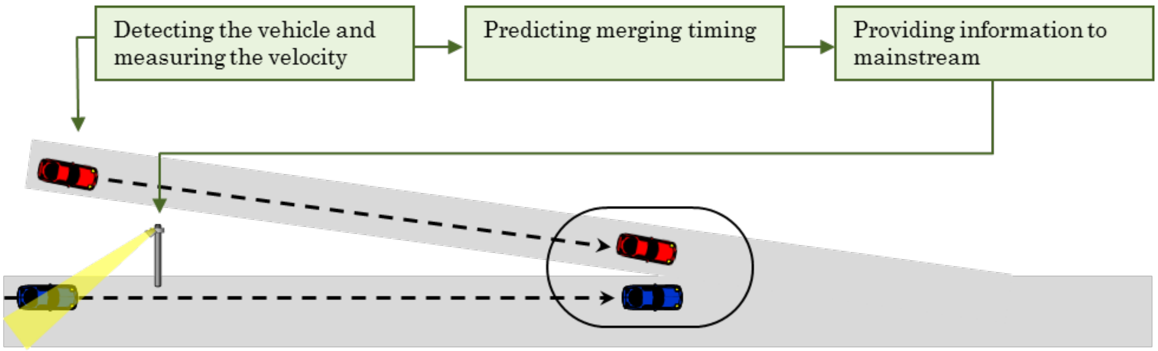


**Figure 5-23: Merging Assistance Example *(Source: MILIM, AHSRA,* Project Report of Advanced Cruise-Assist Highway Systems 2007. *[80])***

### Hypotheses

The service will enhance driver awareness by providing a warning with sound, guidance and graphics to drivers. As a result, the number of accidents will be reduced.

### Performance Measures

- Drivers' understanding level of information and timing of providing information
- Drivers' safety mind
- Drivers' behavior
- Drivers' satisfaction with the service

### Evaluation Approach

The drivers' understanding level of the information, timing of information, change of drivers' safety mind, and their satisfaction were measured by a questionnaire survey.

The speed of vehicles, angular velocity and longitudinal acceleration were measured. The video by the roadside camera was taken at the merging section. The video of the situation of the vehicle ahead and the area around the drivers' feet were taken by an on-board camera.

### Data

- Field operational tests at a merging section in Higashi ikebukuro were conducted from April 23th to May 7th in 2007. Monitor drivers were 50 people between 20-60 years old. The number of field tests was 75 with no service, and 175 with the service.
- Field tests at a merging junction in Tanimachi were conducted from September 18th to 25th in 2007. Monitor drivers were 50 people between 20-60 years old. The number of field tests was 84 with no service, and 191 with the service.

**Key Findings**

Approximately 80% of monitor drivers answered that they could understand the information. Approximately 70-80% of monitor drivers answered that the timing of providing information was good. However, approximately 20-30% of monitor drivers answered that the timing of providing information was late or slightly late. Monitor drivers did not brake suddenly and did not change the lane suddenly. Approximately 70% of monitor drivers answered that the service was useful, so it can be concluded that the service is effective.

**Challenges and Issues**

The warning sound should be improved. Providing information with two steps may improve the service. (After the information of merging section is provided, the information of vehicles at merging section is provided.) More sophisticated evaluation will be needed for practical use.

### 5.2.2.5 Curve Speed Warning

**Evaluation Goal**

The curve speed warning service provides information to drivers who are entering a curve at speeds which are too high to safely negotiate the curve. Sensors are installed upstream of the curve to detect the vehicle and its velocity and to process warning information if speeds exceed a threshold level. The information is transmitted via DSRC to an onboard unit and is also displayed on a VMS located shortly before the curve (Figure 5-24). The FOT was conducted at several curves on the Tokyo Metropolitan Expressway and Hanshin Expressway, as well as on Myodocho curve, Route 6 (Kiyosu line) of the Nagoya Expressway in 2009. The system has been operational since 2009.

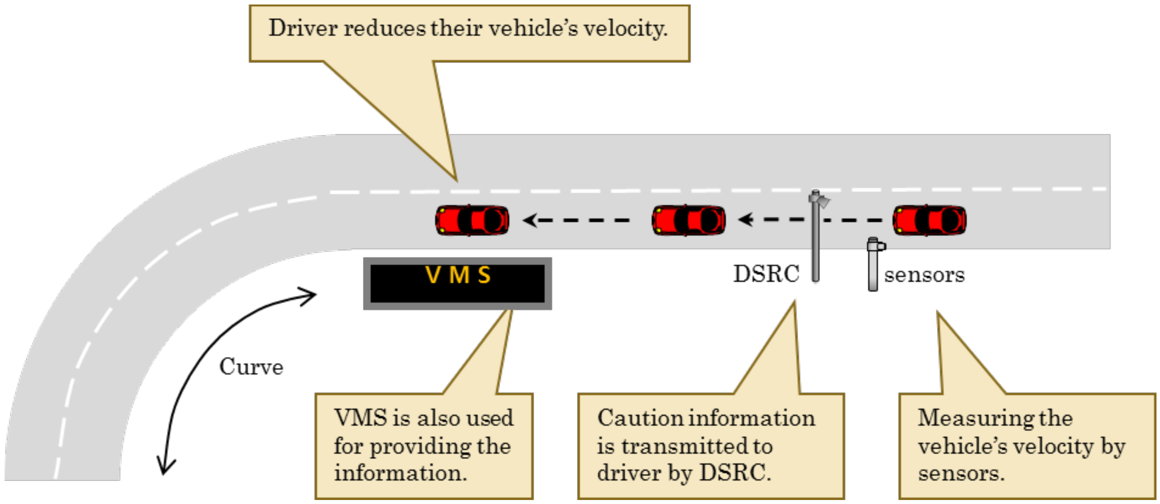


**Figure 5-24: Curve Speed Warning Example *(Source: MILIM, AHSRA,* Project Report of Advanced Cruise-Assist Highway Systems 2008.[79*])***

### Hypotheses

Speeding vehicles just before curve sections may decrease their velocity mildly by providing the warning information of curve sections.

### Performance Measures

- Drivers' understanding level of information
- Drivers' safety mind
- Drivers' behavior and checking their eyes
- Behavior of vehicles

### Evaluation Approach

The drivers' understanding level of information and safety mind were measured by a questionnaire survey. Drivers' eye movements were measured by an eye mark recorder. Behavior of the drivers' head and right foot pedal operations were measured by a gyro sensor. Time, latitude, longitude, vehicles' speed and acceleration were measured by an onboard vehicle device.

### Data

- The field tests were conducted from June 30th to July 29th, and from November 8th to 28th in 2008.
- Monitor drivers were 62 people between 20-60 years old. They conducted the field operational test 6 times. A total of 372 tests were performed.
- The test course was 8.3 km from Fujiidera IC in West Meihan Expressway to Hirano IC in Hanshin Expressway including the Miyake Curve section.
- The radius of the Miyake Curve section is 160m.

**Key Findings**

Approximately 70% of monitor drivers answered that they could understand the information. No monitor drivers felt negative response, when information was provided. When the information was provided, drivers checked dangerous points, decreased their velocity earlier, and curve approaching speed had the tendency to decrease. It can be concluded that the service is effective from the result of the test.

**Challenges and Issues**

Future ways on how to effectively provide information to drivers who did not obey the information of the curve warning should be considered.

#### 5.2.2.6 Ex-ante evaluation and post evaluation of accident reduction effectiveness by using ASV technology (Project by Road Transport Bureau)

**Evaluation Goal**

The goal is to conduct an ex-ante evaluation predicting effectiveness of ASV (advanced Safety Vehicle) via preliminary diffusion of ASV technology and a post evaluation estimating effectiveness of ASV via market results. *[81]*

**Hypotheses**

The effectiveness of ASV can be measured by reduction in the number of accidents calculated by using the nationwide traffic accident statistical data and the parameters representing the subject of ASV or penetration level of ASV in the ex-ante evaluation.

The reduction in the number of accidents can be measured by the number of vehicles equipped with ASV and vehicles not equipped with ASV and the number of accidents by them in the post evaluation.

**Performance Measures**

- Reduction in the number of fatal accidents by using ASV technology
- Reduction in the number of injury accidents by using ASV technology

**Evaluation Approach**

In the ex-ante evaluation, accidents requiring ASV technologies are extracted from the nationwide traffic accident statistics data, and the reduction in the number of fatal accidents and injury accidents by using ASV technology is calculated with the following parameter.

- Parameter1: used to extract the number of accidents needing ASV
- Parameter2: used to extract the number of accidents needing driving assistance
- Parameter3: used to extract the number of accidents which can be prevented by assistance.
- Parameter4: used to figure out the reduction in the number of accidents considering the penetration level of ASV.

In the post evaluation, reduction in the number of accidents by ASV technology is calculated by the accident occurring ratio of vehicles equipped with ASV technology and vehicles not equipped with ASV technology.

**Data**

- From all 2009 traffic accident numbers, 2,426 fatal accidents out of 4,773 and 559,631 injury accidents out of 731,915 were used as the subject of ASV in the ex-ante evaluation.
- The post evaluation requires the following data.
    - The number of vehicles equipped with ASV technology in the market
    - The number of vehicles not equipped with ASV technology in the market
    - The number of accidents by vehicles equipped with ASV technology
    - The number of accidents by vehicles not equipped with ASV technology

**Key Findings**

The reduction in the number of fatal accidents was estimated to be 1,483 and that of injury accidents was estimated to be 307,937 in the ex-ante evaluation. However, after removal of duplication by plural functions, the results indicated a reduction of approximately 1,000 in fatal accidents and 180,000 in injury accidents.

The number of accidents by vehicles equipped with ASV technology and the number of accidents by vehicles not equipped with ASV technology for the post evaluation can be calculated by using the nationwide traffic accident statistical data.

**Challenges and Issues**

The issues for post evaluation is to develop a structure to figure out the number of vehicles equipped with and not equipped with ASV and to store the nationwide traffic accident statistical data in a database where vehicles equipped with ASV and vehicles not equipped with ASV can be easily distinguished.

#### 5.2.2.7 Signal missing/collision prevention support system (Project by National Police Agency)

**Evaluation Goal**

The goal is to evaluate the effectiveness of the collision prevention support system which provides drivers with information through a car navigation system to prevent collision accidents caused by carelessness or misjudgment. *[82]*

**Hypotheses**

Through the car navigation system, attention information is provided two times before the vehicle enters an intersection. Vehicles will decelerate to a safe speed as a result of information provision compared to vehicles without information provision.

**Performance Measures**

- Average speed
- Average deceleration
- Driver's behavior

**Evaluation Approach**

First, the information is provided at 160m from the intersection (Information provision level 1). Secondly, the information is provided if deceleration does not occur even after the vehicle is provided with the information of Level 1 (Information provision level 2). The speed of vehicles was continuously measured between the position where information was provided and the second intersection. Changes in average speed and average deceleration of vehicles were measured.

**Data**

- FOT was conducted at Yamashitabashi intersection in Yokohama.
- The number of "No information provision" samples was 19. The number of "Information provision level 1" samples was 10. The number of "Information provision level 2" samples was 2.

**Key Findings**

The average speed of “information provision Level 2” vehicles was highest in 160m point from the intersection, whereas it was lowest in the subject intersection. The deceleration rate of “information provision Level 2” vehicles was highest. The timing of deceleration of those vehicles was late because the drivers had decelerated to a safe speed after receiving "Information provision Level 2". Thus, it was proved that the system is effective.

#### 5.2.2.8 Stop regulation missing/ crossing collision prevention support system (Project by National Police Agency)

**Evaluation Goal**

The goal is to evaluate the effectiveness of the collision prevention support system which provides drivers with information through a car navigation system to prevent crossing collisions when there is a temporary stop regulation. *[82]*

**Hypotheses**

Through the car navigation system, attention information is provided two times for both vehicles traveling on a main road and a slave road before entering an intersection. Vehicles may decelerate to a safe speed by information provision compared with the case without information provision.

**Performance Measures**

- Average speed
- Average deceleration
- Driver's behavior

**Evaluation Approach**

First, the information is provided at 150m from the intersection for vehicles traveling on a main road (Information provision level 1). Secondly, the information is provided only when it is considered that the traveling conditions for the vehicle are endangered by a vehicle on the side road (Information provision level 2). The information is provided at 120m from the intersection for vehicles traveling on a slave road (Information provision level 1). Next, the information is provided if deceleration does not occur even after the vehicle is provided with the information of Level 1 (Information provision level 2). The speed of vehicles was continuously measured between the position where information was provided and the second intersection in each main road and slave road. Changes in average speed and average deceleration of vehicles were measured.

**Data**

- FOT was conducted at Tekkodanchi exit (provisional name) in Tokyo.
- In main road, the number of "No information provision" samples was 20. The number of "Information provision level 1" samples was 9. The number of "Information provision level 2" samples was 7.
- In slave road, the number of "No information provision" samples was 20. The number of "Information provision level 1" samples was 8. The number of "Information provision level Ⅱ" samples was 5.

**Key Findings**

On the main road, the average speed of "information provision (Levels 1 and 2)" vehicles at the intersection was lower than that of "No information provision" vehicles. On the slave road, the average speed of “information provision Level 2” vehicles was highest when the vehicles passed 120m point from the intersection, whereas it was lowest when the vehicles passed the subject intersection. The deceleration rate of "information provision Level 2" vehicles was highest. The timing of deceleration of those vehicles was late because the drivers had decelerated to a safe speed after receiving "Information provision Level 2". Thus, it was proved that the system is effective.

# 6 Performance Measures and Measurement Methods Used in the U.S. and Japan

This section summarizes the performance measures identified during this collaborative effort, their definitions, and measurement methods in a table format. The table, presented below, contains performance measurements, their definitions, and their measurement methods in both the U.S. and Japan.

## 6.1 Safety Performance Measures/Indicators

**Table 1: Definitions and Measurement Methods: Incident Measures**

| Performance Measure/ Indicator | Definition | | Similar Definition? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Incident Clearance Time | US | Time between when response vehicles arrive at the incident scene and the time at which the last responder has left the scene. [83] | N | Analysis of Accident Database [84] | N |
| | JP | N/A<br>- No definition of "Incident" in Japan | N | N/A | N |
| Incident Duration | US | Time elapsed from the notification of an incident until all evidence of the incident has been removed from the incident scene. [84] | N | Analysis of Accident Database [84] | N |
| | JP | N/A<br>- No definition of "Incident" in Japan | N | N/A | N |
| Incident Response Time | US | The period required for an incident to be identified, verified, and for an appropriate responder(s) equipped to alleviate the interruption to traffic to arrive at the scene. [85] | N | Analysis of Accident Database [84] | N |
| | JP | N/A<br>- No definition of "Incident" in Japan | N | N/A | N |
| Number of Incidents | US | Number of traffic interruptions caused by a crash or other unscheduled event (e.g., vehicle breakdown). [85] | N | Analysis of Accident Database [84] | N |

| Performance Measure/ Indicator | | Definition | Similar Definition? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | N/A<br>- No definition of "Incident" in Japan<br>(Note)<br>Recently, in terms of preventive safety, there are some examples in which traffic safety measures are evaluated using sudden deceleration (over a certain threshold (e.g. -0.3G)) as an indicator. | N | Calculated by acceleration obtained from vehicle probe data | N |
| Roadway Clearance Time | US | The time between first recordable awareness of incident by a responsible agency and first confirmation that all lanes are available for traffic flow. [83] | N | Analysis of Accident Database [84] | N |
| | JP | N/A<br>- It is not utilized as an indicator. | N | N/A | N |
| Weather-related traffic incidents | US | A traffic interruption caused by inclement weather. [84] | N | Analysis of Accident Database [84] | N |
| | JP | N/A(Note)<br>Not utilized as an indicator, however the following references bear relevance.<br>[1] The condition of road surface is collected during each traffic accident investigation.<br>[2] JARTIC (Japan Road Traffic Information Center) is providing information on road closure etc. by continuous rain in a real-time manner. This information can be used as an evaluation indicator by being collected afterward.<br>[3] Car manufacturers and car-navigation manufacturers make and provide information on "passable roads" using probe data in time of disaster. This information can be used for visualization of "passable roads" even after the disaster by being collected afterward. | N | N/A | N |

**Table 2: Definitions and Measurement Methods: Crash Avoidance Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Changes in attentiveness regarding merging vehicles | US | N/A | N | N/A | N |
| | JP | Changes in driver's awareness of upcoming merging vehicles. | N | Interviews and questionnaires are used to survey whether drivers had changes in attentiveness because of the provided information. | |
| Changes in attentiveness regarding upcoming curves | US | N/A | N | N/A | N |
| | JP | Changing driver awareness of upcoming curve segments. | N | Interviews and questionnaires are used to survey whether drivers had changes in attentiveness (increase in awareness of controlling speed) because of the provided information. In addition, a vital sign sensor secondarily measures oxygen saturation degree in blood of the driver in order to more accurately confirm that the intention to accelerate is inhibited by the provided information. This indicator is experimental and requires further study. | |
| Changes in awareness of obstacles | US | N/A | N | N/A | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | Change in driver's awareness of forward obstacles when the OBE provided information. | N | Interviews and questionnaires are used to survey how well drivers understand the content of provided information. A vital sign sensor secondarily measures oxygen saturation degree in blood of the driver in order to detect more accurately whether the information makes the driver tend to reduce the speed. | |
| Changes in travel speed of unequipped vehicles following the equipped vehicles | US | N/A | N | N/A | N |
| | JP | Change in speed of the vehicles that are following OBE equipped vehicles receiving information. | | Image data from roadside cameras is processed to calculate travel speed. | |
| Crash Clearance Time | US | Time between first recordable awareness of a crash by a responsible agency and time at which the last responder has left the scene. [83] | N | Analysis of Incident Management System database [84] | N |
| | JP | N/A(Note)<br>- It is not utilized as an indicator. | N | N/A | |
| Crash Duration | US | Crash duration is calculated from the moment the crash obstructs travel until the incident is cleared (expressed in minutes or hours). [86] | N | Analysis of Incident Management System database [84] | N |
| | JP | N/A<br><br>(Note)<br>- It is not utilized as an indicator. | N | N/A | |
| Crash Response Time | US | The period required for a crash to be identified, verified, and for an appropriate responder to alleviate the interruption to traffic to arrive at the scene. [85] | N | Analysis of Incident Management System database [84] | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | N/A<br><br>(Note)<br>- It is not utilized as an indicator. | N | N/A | |
| Curve speed | US | N/A | N | N/A | N |
| | JP | Vehicle's speed when entering a curved section of roadway. | N | [1] Data from wheel speed sensors is recorded by on-board recording devices.<br>[2] Image data from roadside cameras is processed to calculate travel speed. | |
| Driver Distraction | US | Two general forms of inattention: insufficient inattention and misdirected attention.<br><br>Insufficient attention occurs when the degree to which resources are allocated fails to match that demanded by activities critical for safe driving.<br><br>Misdirected attention occurs when the demands of activities currently critical for safe driving are not matched due to the allocation of resources to other safety critical or non-critical activities. [94] | Y | Driver eye-glance patterns, latitudinal and longitudinal movement, and object avoidance reaction measured with an eye-mark recorder. [94] | Y |
| | JP | The degree to which the driver cannot concentrate on driving. | Y | Eye tracking is used to measure the time and frequency of distraction. We alternatively use this method because we do not have an appropriate method to easily measure driver concentration. | |
| Frequency of looking out ahead and appropriate direction | US | N/A | N | N/A | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | Frequency of drivers eyes on forward roadway and appropriate direction during driving. | N | Eye tracking is used to measure the time and frequency of looking ahead. We alternatively use this method because of the technical constraints of using an eye tracking camera for motion detection. | |
| Level of understanding of provided information | US | N/A | N | N/A | N |
| | JP | Level of driver's understanding of information provided by OBE, which provides information on road and traffic conditions ahead. | | Interviews and questionnaires are used to survey how well drivers understand the content of provided information. | |
| Location where brakes are applied | US | N/A | N | N/A | N |
| | JP | The roadway location where the driver removes his foot from the throttle and moves it to the brake | N | Foot movements are captured by onboard cameras, and this data is used to calculate the roadway location where the foot was moved to the brake. | |
| Number of accidents (US: Number of crashes) | US | The number of crashes occurring on or near a roadway, regardless of the number of vehicles involved. [84] | Y | Analysis of Accident Database [84] | Y |
| | JP | The number of traffic accidents. | Y | Statistical data on injury or deaths obtained from the Traffic Police and on property damage obtained from the road administrator. | |
| Post-warning deceleration | US | N/A | N | N/A | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | Rate of deceleration following OBE cautionary warning. | N | Data from wheel speed sensors and acceleration sensors is recorded by on-board recording devices. | |
| Rate of deceleration when encountering obstacles | US | N/A | N | N/A | N |
| | JP | Rate of deceleration at the time the driver discovers obstacles ahead on the roadway. | N | [1] Data from acceleration sensors is recorded by on-board recording devices.<br>[2] Image data from roadside cameras is processed to calculate deceleration. | |
| Rate of lane departures | US | N/A | N | N/A | N |
| | JP | The reduction in the rate of lane departures at the curve due to information provision regarding oncoming vehicles and curve speed warnings. | N | Measured by roadside camera. | |
| Speed when entering sections with poor visibility | US | N/A | N | N/A | N |
| | JP | Vehicle's speed when it enters a road section with poor visibility. | N | [1] Data from wheel speed sensors and acceleration sensors is recorded by on-board recording devices.<br>[2] Image data from roadside cameras is processed to calculate travel speed. | |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Subjective assessment of level of effectiveness | US | N/A | N | N/A | N |
| | JP | Driver opinion of OBE information effectiveness. | N | Interviews and questionnaires are used to survey whether drivers felt that the supplied information was helpful for safer driving. | |
| Time between merging vehicles ahead and vehicles behind them on the main road | US | N/A | N | N/A | N |
| | JP | The time interval between the forward merging vehicle and the trailing vehicle on the main road. | N | Roadside cameras capture a bird's-eye view of the merge area for measurement of the time between merging vehicles ahead and vehicles on the main route. | |

**Table 3: Definitions and Measurement Methods: Vehicle Safety Measures**

<table>
<tr><th>Performance Measure/ Indicator</th><th colspan="2">Definition</th><th>Same Definition in Both Countries?</th><th>Measurement Method</th><th>Similar Method?</th></tr>
<tr><td rowspan="2">Commercial Vehicle Safety Violations</td><td>US</td><td>Number of violations issued by law enforcement based on vehicle weight, size or safety. [85]</td><td>Y</td><td>Analysis of Accident Database [84]</td><td rowspan="2">Y</td></tr>
<tr><td>JP</td><td>Number of identified violations issued by law enforcement according to<br>- Vehicle's gross weight and size (width, length and height) <Factor of Vehicle><br>- Vehicle with special feature freight that cannot be divided into several parts <Factor of Freight></td><td>Y</td><td>Documents of Road Operators</td></tr>
<tr><td rowspan="2">Security for highway and transit</td><td>US</td><td>The number of violations issued by law enforcement for acts of violence against travelers. [85]</td><td>Y</td><td>Analysis of Accident Database [84]</td><td rowspan="2">Y</td></tr>
<tr><td>JP</td><td>The number of violations issued by law enforcement for acts of violence against drivers.</td><td>Y</td><td>Documents of Traffic Police</td></tr>
</table>

**Table 4: Definitions and Measurement Methods: Transit Retrofit Package (TRP) Safety Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Response Time | US | The number of seconds between when the alert was issued to the driver and when the driver first engaged the brake pedal. [87] | N | Analysis of data collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. [87] | N |
| | JP | N/A | N | N/A | |
| TTC at Brake Onset | US | From the time the TRP driver responds to the alert, the instantaneous number of seconds until the host vehicle comes into contact with the remote vehicle. [87] | | Analysis of data collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. [87] | N |
| | JP | N/A | N | N/A | |
| Peak Deceleration | US | The highest level of deceleration achieved by the bus during the braking event. [87] | | Analysis of data collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. [87] | N |
| | JP | N/A | N | N/A | |
| Mean Deceleration | US | The average braking level over the duration of the entire braking event; a measure of the severity of a braking event. [87] | | Analysis of data collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. [87] | N |
| | JP | N/A | N | N/A | |
| Minimum TTC | US | The shortest TTC observed during a braking event; represents the maximum level of severity of the event. [87] | | Analysis of data collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. [87] | N |
| | JP | N/A | N | N/A | |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Frequency of Response | US | The percentage of alerts that successfully prompt a response from the driver. [87] | | Analysis of data collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. [87] | N |
| | JP | N/A | N | N/A | |
| Lateral Acceleration | US | Driver's aggressiveness in navigating a curve. [87] | | Analysis of data collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. [87] | N |
| | JP | N/A | N | N/A | |

## 6.2 Sustainability Performance Measures/Indicators

**Table 5: Definitions and Measurement Methods: Sustainability Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Emissions | US | The predicted emissions for each pollutant type on a transportation facility or network. [4] | Y | See measurement methods for Vehicle Miles Traveled (VMT). Reduction in VMT can be multiplied by the average emissions per vehicle per mile to estimate the average reduction in emissions. Alternately, VMT may be used as input into an EPA model (e.g., MOBILE 6.2) to generate emissions. [4] | Y |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | The predicted $CO_2$ emissions on the road network in large Metropolitan city. | Y | By using computer traffic simulation, each vehicle's driving behaviors are simulated. Total $CO_2$ emissions are estimated by calculating the $CO_2$ emissions for each vehicle by using driving patterns and $CO_2$ emission database that include the relation of vehicle velocity and $CO_2$ emission for each vehicle category. | |
| Fuel Consumption | US | The fuel consumption rate associated with the use of a transportation facility or network. [4] | Y | See measurement methods for Vehicle Miles Traveled (VMT). Reduction in VMT can be multiplied by the average fuel consumption by a vehicle per mile to estimate the average reduction in fuel consumption. Alternately, VMT may be used as input into an EPA model (e.g., MOBILE 6.2) to generate fuel consumption. [4] | N |
| | JP | The fuel consumption rate associated with the use of a transportation facility or network. | Y | Automobile Fuel Consumption Census by MLIT | |

## 6.3 Mobility Performance Measures/Indicators

**Table 6: Definitions and Measurement Methods: Congestion Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Delay | US | Additional travel time experienced by travelers at speeds less than the free flow speed (expressed in seconds or minutes). [86] | Y | See measurement methods for Travel Time – Facility. Delay is calculated as the difference between the measured travel time and the travel time at free-flow speeds. [85] | Y |
| | JP | Additional travel time experienced by travelers at speeds less than the free flow speed (expressed in seconds or minutes). | Y | Delay is calculated as the difference between the measured travel time and the travel time at free-flow speeds. | |
| Demand | US | Demand is defined as the number of vehicles and the percentage of vehicles of each type that wish to traverse the study area. [86] | Y | Travel demand models [86] | Y |
| | JP | Demand is defined as the number of vehicles and the percentage of vehicles of eftach type that wish to traverse the study area. | Y | 1. Travel demand models<br>2. Screen line investigation | |
| Extent of Congestion – Spatial | US | Miles of roadway within a predefined area and time period for which average travel times are 30% longer than unconstrained (free flow) travel times. [84] | N | See measurement methods for Travel Time – Facility. [84] | Y |
| | JP | Travel speed is measured for a certain road section. In arterial roads, 20km/h or lower is defined as “crowded”, and 10km/h or lower is defined as “congested”. The product of the duration multiplied by the length of the road section is defined as “congestion degree” (unit: km*h). | N | See measurement methods for Travel Time – Facility. | |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Extent of Congestion – Temporal | US | The time duration during which more than 20% of the roadway sections in a predefined area are congested. [84] | N | See measurement methods for Travel Time – Facility. [84] | Y |
| | JP | Travel speed is measured for a certain road section. In arterial roads, 20km/h or lower is defined as "crowded", and 10km/h or lower is defined as "congested". The product of the duration multiplied by the length of the road section is defined as "congestion degree" (unit: km*h). | N | See measurement methods for Travel Time – Facility. | |
| Free flow speed | US | Free flow speeds are those observed from vehicles whose operations are unimpeded by traffic control devices (e.g., ramp meters) or by other vehicles in the traffic stream. [88] | Y | 1. 85th percentile speed reported by fixed sensors during off peak periods. [84]<br>2. Posted speed limit [84] | Y |
| | JP | Free flow speeds are those observed from vehicles whose operations are unimpeded by other vehicles in the traffic stream. | Y | 1. 90th percentile speed reported by vehicle probe technologies during off peak periods.<br>2. Posted speed limit | |
| Level of Service (LOS) | US | Qualitative measure describing operational conditions within a traffic stream based on service measures, such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience. Ranges from LOS A (best) to LOS F (worst). [86] | N | The measurement of HCM LOS utilizes the measures described for speed, delay, and density for freeways, arterials and intersections. For two-lane highways, the percent time following is estimated by measuring the percent of vehicles in platoons passing a given point for the peak 15 minute flow period within the analysis hour. The percent of vehicles in platoon is assumed to be roughly equal to the percent time spent following. [85] | N |

| Performance Measure/ Indicator | Definition | | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | N/A<br><br>(Note)<br>There is a similar idea to LOS in Japan, VICS (Vehicle Information and Communication System). VICS is a nationwide system that real time road traffic information such as traffic congestion information, traffic enforcement and so on is provided to drivers via several medias. VICS categorizes road traffic condition into three categories, namely “Traffic Jam”, “Traffic Congestion” and “Normal” according to the observed traffic speed of the section. | N | N/A | |
| Oversaturation | US | If the observed density is greater than the density at capacity, then the freeway is considered to be oversaturated or in “breakdown” condition. [85] | Y | See measurement methods for Density. [85] | Y |
| | JP | If the observed density is greater than the density at capacity, then the freeway is considered to be oversaturated or in “breakdown” condition. | Y | Documents of Road Operators | |
| Percent Congested Travel | US | The percent of vehicle miles or person miles traveled in congested conditions. [85] | N | See measurement methods for Travel Time – Facility. [84] | N |
| | JP | N/A | N | N/A | |
| Queue | US | This represents a line of vehicles waiting to be served by the system. The internal queue dynamics can involve starts and stops. [85] | Y | A vehicle is considered as queued when it approaches within one car length of a stopped vehicle and is itself about to stop. [85] | Y |
| | JP | This represents a line of vehicles waiting to be served by the system. The internal queue dynamics can involve starts and stops. | Y | A vehicle is considered as queued when it approaches within one car length of a stopped vehicle and is itself about to stop. | |
| Queue Length | US | Number of vehicles in queued state. [85] | N | See measurement method for Queue. [85] | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | Length of Queue (in distance, not number of vehicles). | N | [1] Storage length survey<br>Distance between the stop line and the tail end of the queue is measured when the light of the observed inflow section turns from red to green.<br><br>2] Congestion length survey<br>In the case vehicles measured in [1] remain even after the light turns from green to red, the distance between the stop line and the tail end of the queue is measured. | |
| Shockwave | US | Shockwaves can be defined as transition zones between two traffic states (e.g., from free-flow to congestion) that move through a traffic environment like a propagating wave. [89] | Y | Measuring and detecting shockwaves requires data on individual vehicle movements and interactions over time and space. Such data are very limited and usually only available for short sections of roadways as part of traffic studies for specific road segments. Connected vehicle technologies, however, would enable the collection of the kinds of vehicle-level data necessary for fine-grain shockwave detection and analysis because each connected vehicle can act as a vehicle-level traffic conditions monitor. [89] | N |
| | JP | Shockwaves can be defined as transition zones between two traffic states (e.g., from free-flow to congestion) that move through a traffic environment like a propagating wave. | Y | Video camera survey: the tail point of the traffic jam is manually identified using data collected by video movies. | |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Space Mean Speed | US | Arithmetic mean of the speed of those vehicles occupying a given length of road at a given instant. It is also defined as the harmonic mean of speeds passing a point over a period of time. [95] | Y | 1. Speeds are estimated from vehicle probe technologies.<br>2. Fixed sensors calculate harmonic mean of speeds reported by a fixed sensor for a given period of time. [95] | Y |
| | JP | Arithmetic mean of the speed of those vehicles occupying a given length of road at a given instant. It is also defined as the harmonic mean of speeds passing a point over a period of time. | Y | 1. Speeds from fixed sensors are polled continuously. Travel times are estimated from the speeds and reported every 5 minutes in case of Tokyo Metropolitan Expressway.<br>2. Vehicle probe technologies: Travel times are estimated and reported out using data collected by ITS Spot. (every 15 minutes as of now) | |
| Throughput – Person | US | Number of persons, including vehicle occupants, pedestrians, and bicyclists, traversing a roadway section in one direction per unit of time. May also be defined as the number of persons traversing a screen line in one direction per unit of time. [84] | N | Vehicle Occupancy Surveys [84] | N |
| | JP | N/A<br><br>(Note)<br>The Survey of Road Traffic Census collects the number of pedestrians and bicycles for 36,000 sections nationwide every 5 years.<br>There are no surveys collecting the number of vehicle occupants inside each vehicle. | N | N/A | |
| Throughput – Vehicle | US | Number of vehicles traversing a roadway section in one direction per unit time. May also be defined as the number of vehicles traversing a screen line in one direction per unit time [84]. | Y | Analysis of data from spot vehicle counters [84]. | Y |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | Number of vehicles traversing a roadway section in one direction per unit time. May also be defined as the number of vehicles traversing a screen line in one direction per unit time. | Y | 1. The data is collected in 36,000 sections nationwide by the Road Traffic Census which covers arterial roads every 5 years.<br>2. There are approximately 500 continuous traffic observation equipment units deployed on highways nationwide.<br>3. Fixed sensors are installed mainly on urban expressways and inter-city expressways with large traffic volume | |
| Time Mean Speed | US | Arithmetic mean of the speed of vehicles passing a point during a given time interval. [95] | Y | Speeds are polled continuously from fixed sensors, and arithmetic mean is calculated. [95] | Y |
| | JP | Arithmetic mean of the speed of vehicles passing a point during a given time interval. | Y | Speeds from fixed sensors are polled continuously. Travel times are estimated from the speeds and reported every 5 minutes in case of Tokyo Metropolitan Expressway. | |
| Travel Time – Facility | US | The average time required to traverse a section of roadway or other facility in a single direction. [84] | Y | 1. Speeds from fixed sensors are polled continuously, every 20 seconds, or every 5 minutes. Travel times are estimated from the speeds and reported every 5 to 15 minutes. [84]<br>2. Vehicle probe technologies: Travel times are estimated and reported out every 1-15 minutes using data from toll tag transponders, fleet GPS, cell phone probes. [84] | Y |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | The average time required to traverse a section of roadway or other facility in a single direction. | Y | 1. On-road survey: A hired test vehicle actually passes a target section and its travel time on each section is measured. This nationwide survey is conducted every 5 years on major arterial roads. The number of sections is about 36,000 nationwide.<br>2. Fixed sensors: Speeds from fixed sensors are polled continuously. Travel times are estimated from the speeds and reported every 5 minutes in case of Tokyo Metropolitan Expressway.<br>3. Vehicle probe data collected every 15 minutes by ITS Spot | |
| Vehicle Miles Traveled (VMT) or Person Miles Traveled (PMT) | US | The total distance travelled by all vehicles or persons on a transportation facility or network during a specified period of time (expressed in miles). [86] | Y | See measurement method for Volume. VMT for each facility is calculated by multiplying the facility length with the facility volume. Facility VMTs are aggregated to give the total VMT for the network. Both measures are calculated over a specific period of time. [4] | N |
| | JP | The total distance travelled by all vehicles or persons on a transportation facility or network during a specified period of time (expressed in hours).<br>- Vehicle Kilometers Traveled is used as a unit.<br>- Person Kilometers Traveled is not often utilized. | Y | Calculated by the observed traffic volume and section length. | |
| Volume | US | The number of persons or vehicles passing a point on a roadway during some time interval (expressed in vehicles or persons per hour). [86] | Y | Analysis of volume data from fixed sensors. [86] | Y |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | The number of persons or vehicles passing a point on a roadway during some time interval (expressed in vehicles or persons per hour). | Y | <Vehicles, Motorcycles, Bicycles and Pedestrians><br>The data is collected in 36,000 sections nationwide by the Road Traffic Census which covers arterial roads every 5 years.<br><br><Vehicles Only><br><br>- There are approximately 500 continuous traffic observation equipment units that are deployed on highways nationwide.<br><br>- Fixed sensors are installed mainly on urban expressways and inter-city expressways with large traffic volume | |
| Volume to Capacity (V/C) Ratio | US | The ratio of flow rate to capacity for a transportation facility. [86] | Y | If the demand exceeds capacity for at least 15 consecutive minutes, then the capacity can be measured in the field. Capacity is the queue discharge flow rate observed for at least 15 consecutive minutes. [85] | Y |
| | JP | The ratio of flow rate to capacity for a transportation facility. | Y | Calculated ratio of traffic capacity and observed traffic volume calculated based on documents of Road Operators. Usually it is calculated in 1 hour units. | |

**Table 7: Definitions and Measurement Methods: Reliability Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| 95th (or 90th) percentile travel time | US | Estimates how bad delay will be on specific routes during the heaviest travel days. The one or two bad days each month mark the 95th or 90th percentile days, respectively. [91] | Y | This is calculated as the 95th (or 90th) percentile travel time for specific routes or trips. [91] | Y |
| | JP | Estimates how bad delay will be on specific routes during the heaviest travel days. The one or two bad days each month mark the 95th or 90th percentile days, respectively. | Y | This is calculated as the 95th (or 90th) percentile travel time for specific routes or trips. | |
| Buffer Index | US | This represents the extra time travelers need to add to their average trip time to ensure an on-time arrival. [91] | Y | See measurement methods for Travel Time – Facility. [84] Buffer Index = Planning time index - average travel time index. [91] | Y |
| | JP | This represents the extra time travelers need to add to their average trip time to ensure an on-time arrival. | Y | See measurement methods for Travel Time – Facility. Buffer Index = Planning time index - average travel time index | |
| Planning Time Index | US | This represents the total time a traveler should allow to ensure on-time arrival. [91] | Y | See measurement methods for Travel Time – Facility. [84] Planning index time = 95th percentile Travel time / free-flow travel time [91] | Y |
| | JP | This represents the total time a traveler should allow to ensure on-time arrival. | Y | See measurement methods for Travel Time – Facility. Planning index time = 95th percentile Travel time / free-flow travel time | |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Reliable Throughput | US | Reliable throughput is defined as traveler trips or traveler miles delivered reliably by the system. [92] | N | See measurement methods for Travel Time – Facility. [84] Reliable traveler trips should be computed as the total number of trips with travel times less than or equal to the 95th percentile travel time for that trip. Reliable traveler miles delivered should be computed as the total miles traveled on the reliable trips. | N |
| | JP | N/A<br>(Note)<br>- It is not utilized as an indicator. | N | N/A | |
| Travel Time Index | US | This represents the additional time required to make a trip during peak periods. The additional time required is a result of increased traffic volumes on the roadway and the additional delay caused by crashes, poor weather, special events, or other nonrecurring incidents. [91] | Y | See measurement methods for Travel Time – Facility. [84] Travel Time Index = Average peak period travel time / free-flow travel time. [91] | Y |
| | JP | This represents the additional time required to make a trip during peak periods. The additional time required is a result of increased traffic volumes on the roadway and the additional delay caused by crashes, poor weather, special events, or other nonrecurring incidents. | Y | See measurement methods for Travel Time – Facility. Travel Time Index = Average peak period travel time / free-flow travel time. | |

**Table 8: Definitions and Measurement Methods: Time Efficiency Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Travel time reduction | US | N/A | N | N/A | N |
| | JP | Travel time reduction by reducing traffic congestion. | N | Computer simulation of the whole of the Tokyo metropolitan express way. | |

**Table 9: Definitions and Measurement Methods: Capacity Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Capacity | US | Capacity of a facility is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform sections of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. [93] | Y | Capacity can be measured in the field on any street segment immediately downstream of a queue of vehicles. The analyst would simply count the vehicles passing a point on the downstream segment for 1 hour (or for a lesser time period if the queue does not persist for a full hour) to obtain the segment capacity. [93] | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | Capacity of a facility is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform sections of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. | Y | It is determined during design stage (for new road construction, improvement and upgrading) and is not a measured item. | |
| Density | US | Number of vehicles per lane per period [85] | Y | The average density over time at a given point in space is computed by dividing the measured flow rate per hour by the measured arithmetic mean speed at the point. The average density over the length of a segment at a given point in time is measured using aerial photography and counting the number of vehicles present on the segment. [85] | Y |
| | JP | Number of vehicles per lane per period<br><br>The indicator represents road condition roughly as follows.<br>1.00 or less: Vehicles can travel smoothly without any congestion.<br>1.00-1.25: Although road is likely to be congested for 1-2 hours, less likely to be congested for hours.<br>1.25-1.75: Time zone of congestion is likely to increase rapidly around peak time.<br>1.75-2.00: Chronic congestion where time of congestion reaches around 50% of 12-hour daytime.<br>2.00 or more: Chronic congestion where time of congestion reaches around 70% of 12-hour daytime | Y | ((Observed traffic volume of 12-hour daytime) *(Correction coefficient by large vehicle ratio)) divided by (design traffic capacity of 12-hour daytime) [Road traffic census] | |

**Table 10: Definitions and Measurement Methods: Transit Measures**

| Performance Measure/ Indicator | Definition | | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Bus on-time performance | US | The percentage of bus arrivals that fall within a specified threshold of the scheduled arrival time. | Y | Analysis of transit records. | Y |
| | JP | The percentage of bus arrivals that fall within a specified threshold of the scheduled arrival time. | Y | Analysis of records of bus operators. | Y |
| Bus throughput | US | The number of buses operating along a given corridor during a given time period. | N | Analysis of transit records. | N |
| | JP | N/A | N | N/A | |
| Park-and-ride lot daily usage | US | The average number of parking spaces occupied at a park-and-ride lot (weekdays). | N | Analysis of park-and-ride records. | N |
| | JP | N/A<br><br>(Note)<br>The similar idea is to count the number of park-and-ride users. | N | N/A<br><br>Note)<br>Parking lot utilization survey is carried out. However, parking spaces are not only for park-and-ride, but also for other purposes. | N |
| Ridership | US | The number of passengers on the transit system being evaluated. | Y | Analysis of transit records. | Y |

| Performance Measure/ Indicator | Definition | | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | The number of passengers on the transit system or transferred passengers from individual transport. | Y | Ridership can be confirmed by statistics on the number of users by transportation in major 3 metropolitan areas. [Yearbook of Urban Transport] | Y |
| Total annual regional transit ridership | US | The total number of trips taken on all transit services in the region. | Y | Analysis of transit records. | Y |
| | JP | The total number of trips taken on all transit services in the region or transferred passengers from individual transport. | Y | Ridership can be confirmed by statistics on the number of users by transportation in major 3 metropolitan areas. [Yearbook of Urban transport] | Y |
| Travel time savings (bus) | US | The amount of time (in seconds) of travel time per bus run saved from pre-deployment to post-deployment. | Y | Analysis of transit records. | Y |
| | JP | The amount of time (in seconds) of travel time per bus run saved from pre-deployment to post-deployment. | Y | Analysis of records of bus operators. | Y |

**Table 11: Definitions and Measurement Methods: Traveler Behavior Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Departure Time Changes | US | Represents changes in the trip start time. [86] | Y | Travel demand models, activity based models, mesoscopic models. [86] | N |
| | JP | Represents changes in the trip start time. | Y | Questionnaire survey. | N |
| Destination changes | US | Represents changes to travel destinations. [86] | Y | Travel demand models, activity based models, mesoscopic models. [86] | Y |
| | JP | Represents changes to travel destinations. | Y | Travel demand models. | Y |
| Induced/ Foregone Demand | US | Estimates new trips (induced demand) or foregone (cancelled or skipped) trips resulting from the implementation of traffic management strategies. [86] | N | Travel demand models, activity based models, mesoscopic models. [86] | N |
| | JP | N/A<br><br>(Note)<br>The idea exists, but a concrete measurement method is not available. | N | N/A | N |
| Modal Split | US | The percentage of travelers using each travel mode (SOV, HOV, transit, bicycle, pedestrian, etc.). [86] | Y | Travel demand models, activity based models. [86] | Y |

| Performance Measure/ Indicator | Definition | | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | The percentage of travelers using each travel mode (Rail, Public Bus, Bicycle, Pedestrian, etc.). | Y | [1] National Statistics by MLIT<br>[2] Travel demand models | Y |
| Mode Shift | US | Mode shift captures changes regarding the selection of travel modes. [86] | Y | Travel demand models, activity based models. [86] | Y |
| | JP | Mode shift captures changes regarding the selection of travel modes. | Y | Travel demand models. | Y |
| Route Diversion | US | Captures changes in travel routes, including pre-trip route diversion and enroute diversion. [86] | Y | Travel demand models, activity based models, mesoscopic models. [86] | Y |
| | JP | Captures changes in travel routes, including pre-trip route diversion and enroute diversion. | Y | [1] Travel demand models<br>[2] Probe Data (The detailed measuring method is not available now, but will be available in the future.) | Y |
| Traveler Response (US) / Change in Transport Behavior (JP) | US | Includes route diversion, departure time choice, mode shift, destination choice, and induced/foregone demand. [86] | Y | Travel demand models, activity based models, mesoscopic models. [86] | Y |
| | JP | Includes route diversion, departure time choice, mode shift, destination choice, and induced/foregone demand. | Y | Travel demand models. | Y |

**Table 12: Definitions and Measurement Methods: Tolling Measures**

| Performance Measure/ Indicator | Definition | | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Amount of Diverted Vehicles | US | The number of vehicles which are diverted to an alternate route or different time period by tolling measure(s). Can also be alternately defined as the probability of diversion when tolling is in place. | Y | Models such as the Voyager system (employed by North Carolina DOT) calculate probably of diversion and changes in volume by utilizing metrics such as differences in travel times and costs. | N |
| | JP | The number of vehicles which are diverted to an alternate route or different time period by tolling measure(s). | Y | Traffic volume count by route or by time period. | N |
| Air Quality Indicators | US | Concentration of emissions such as volatile organic compounds (VOCs), nitrogen oxides (NOx), carbon monoxide (CO), particulate matter (PM), and other pollutants. | Y | Tools such as the EPA's MOVES2014 allow for location-specific collection of air quality and emission data. | Y |
| | JP | NOx Concentration and suspended PM concentration in air. | Y | As usual method counting those indicators (Effect of weather is difficult to distinguish for the purposes of evaluation). | Y |
| Cordon Pricing Revenue | US | Dollars generated from tolls to enter a specific congested area, usually a city center. | N | Analysis of electronic tolling transponder data. | N |

| Performance Measure/ Indicator | Definition | | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | N/A<br><br>(Note)<br>Revenue change by tolling measures is not measured. | N | N/A | N |
| HOT Lane Frequency of Use | US | The count of trips in HOT lanes during each analysis period. | N | Analysis of electronic tolling transponder data and HOT lane monitoring reports. | N |
| | JP | N/A<br><br>(Note)<br>No HOT lanes in Japan | N | N/A | N |
| Toll Revenue | US | Dollars generated from tolls on managed roadways (toll roads) and managed lanes (Express or HOT lanes), including variable priced facilities. | N | Analysis of electronic tolling transponder data and HOT lane monitoring reports. | N |
| | JP | N/A<br><br>(Note)<br>No HOT lanes in Japan | N | N/A | N |
| Variable Priced Toll Revenue | US | Dollars generated from variably priced tolls, higher tolls are charged during higher congestion, lower tolls and lower congestion. | N | Analysis of electronic tolling transponder data and HOT lane monitoring reports. | N |
| | JP | N/A<br><br>(Note)<br>Revenue change by tolling measures is not measured. | N | N/A | N |

**Table 13: Definitions and Measurement Methods: User Satisfaction Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| User Satisfaction | US | This is a measure or indicator of how products or services meet or exceed the user's (customer's) expectations. | Y | User surveys. | Y |
| | JP | This is a measure or indicator of how products or services meet or exceed the user's (customer's) expectations. | Y | User surveys. | Y |

**Table 14: Definitions and Measurement Methods: Institutional and Organizational Analysis Measures**

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Change In The Number And Level Of New Regional Agreements | US | The change in the number and level of new regional agreements between agencies in support of a joint deployment. [90] | N | Analysis and summarization of pre- and post-deployment interviews and program documents. [90] | N |
| | JP | N/A | N | N/A | N |
| Percentage Of "Total" And "Active" Agencies Participating In ICM | US | The percentage of "total" and "active" agencies participating in an ICM or other deployment. [90] | N | Analysis and summarization of pre- and post-deployment interviews and program documents. [90] | N |
| | JP | N/A | N | N/A | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Changes In Perceptions Of Deployment Agencies On Efficacy And Satisfaction Of Arrangements | US | Observed changes in perceptions of deployment agencies on efficacy and satisfaction of cooperative arrangements. [90] | N | Analysis and summarization of pre- and post-deployment interviews and program documents. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In Perceptions Of USDOT On The Efficacy And Satisfaction Of Arrangements | US | Changes in perceptions within the USDOT on the efficacy and satisfaction of arrangements. [90] | N | Analysis and summarization of pre- and post-deployment interviews and program documents. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In Decision Making Roles And Responsibility | US | Any changes in decision making roles and responsibilities that occurred on an institutional level during the cooperative deployment. [90] | N | Analysis and summarization of pre- and post-deployment interviews and program documents. [90] | N |
| | JP | N/A | N | N/A | N |
| Change In Number Of Comms. Between Transportation Partners | US | Changes in the number and frequency of communications between transportation partners. [90] | N | Tracking of ICMS communications and data logs. [90] | N |
| | JP | N/A | N | N/A | N |
| Perceptions Of Level Of Comfort In The Capacity To Use ICM During Complex Situations | US | A qualitative estimation of the comfort of transportation operators to utilize ICM during complex situation and conditions. [90] | N | Summarization of post-deployment interviews. [90] | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| | JP | N/A | N | N/A | N |
| Perceptions And Comfort Level With Inter-Agency Device Control And Sharing | US | A qualitative estimation of operator perceptions and comfort level with inter-agency device control and sharing. [90] | N | Summarization of post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |
| Reduction In The Percentage Of Time Spent On Routine Issues | US | Observed reduction in the percentage of time spent on routine operational issues. [90] | N | Analysis of ICM logs and pre- and post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In Conflict Identification, Logging, And Resolution Approaches | US | Post-deployment changes in conflict identification, logging, and resolution approaches. [90] | N | Analysis of ICM logs and pre- and post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |
| Development Of A Regionally Agreed Upon Shared Vision | US | Observation of if an ICM deployment results in a common region vision. [90] | N | Post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In Organization And Institutional Structures | US | Changes in partner agency organizational and institutional structures as a result of ICM deployment. [90] | N | Analysis and summarization of pre- & post-deployment interviews and program documents [90] | N |
| | JP | N/A | N | N/A | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Number Of Predefined Strategies For Coordinated Action | US | The number of predefined strategies for coordinated action developed as a result of the ICM deployment. [90] | N | Pre-defined strategy list from Mobility Analysis situational awareness data. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In The Situational Awareness Capabilities Of Partner Agencies | US | Changes in the situational awareness capabilities of partner agencies as a result of an ICM deployment [90] | N | Results from the conducted Mobility Analysis. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In Agency Perceptions Of The ICM Over The Demonstration Phase | US | Changes in partner agency perceptions of the ICM deployment over the demonstration phase. [90] | N | Post-deployment interview summaries. [90] | N |
| | JP | N/A | N | N/A | N |
| Level Of Agency Acceptance And Use Of ICMS | US | Level of agency acceptance and use of the ICM system. [90] | N | Post-deployment interview summaries. [90] | N |
| | JP | N/A | N | N/A | N |
| Reliability And Value Assessment Of ICMS And Other Tools | US | Post-deployment evaluation of the reliability and value of ICMS and other tools. [90] | N | Post-deployment interview summaries. [90] | N |
| | JP | N/A | N | N/A | N |
| Diversity And Stability Of Funding Beyond The Demonstration Phase For ICM | US | Assessment of the availability and stability of funding sources in order to sustain ICM beyond the demonstration phase. [90] | N | Agency self-assessment of sustainability from post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |

| Performance Measure/ Indicator | | Definition | Same Definition in Both Countries? | Measurement Method | Similar Method? |
|---|---|---|---|---|---|
| Incorporation Of Organizational Structures And Personnel Requirements Into Agency Budgets | US | A sustainability assessment of the Incorporation of organizational structures and personnel requirements into agency budgets. [90] | N | Agency self-assessment of sustainability from post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In O&M Practices To Focus On Corridor-Critical Resources | US | Assessment of changes in operations and maintenance practices to emphasize focus on corridor-critical resources. [90] | N | Agency self-assessment of sustainability from post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |
| Changes In Performance Assessment Approaches Reported By Partner Agencies | US | Observed changes in performance assessment approaches reported by partner agencies. [90] | N | Interview summaries from post-deployment interviews. [90] | N |
| | JP | N/A | N | N/A | N |
| Increase In The Number And Nature Of Comms. Between Transportation Partners For Daily Operations | US | Tracked increases in the number and nature of communications between transportation partners for daily operations. [90] | N | Tracking of ICM data logs of communications. [90] | N |
| | JP | N/A | N | N/A | N |
| Incorporation Of Lessons Learned Into Knowledge And Tech Transfer Activities | US | Ongoing/iterative incorporation of lessons learned into knowledge and technology transfer activities. [90] | N | Pre- and post-deployment interviews, workshops, and case studies. [90] | N |
| | JP | N/A | N | N/A | N |

# 7 Comparison of Evaluation Tools and Methods Used in the U.S. and Japan

This section provides a summary assessment of the evaluation tools and methods discussed in Section 5, and performance measures and their measurement methods discussed in Section 6. This section also identifies the lessons learned with respect to evaluations.

## 7.1 Summary Assessment

- Evaluations in the U.S. were mostly conducted by an independent evaluator as evaluations of pilot demonstrations and small-scale field tests, and AMS-based evaluations, whereas in Japan evaluations were mostly conducted as FOTs.
- Very few evaluations examined the longer-range impacts of cooperative systems.
- There was limited discussion on how lack of driver behaviors in the presence of cooperative systems was incorporated in the impacts assessment.
- Neither the U.S. nor Japan applied rigorous experimental designs to isolate impacts of multiple services or applications.
- There is lack of common definitions for performance measures and methods for estimating them between the U.S. and Japan.

## 7.2 Lessons Learned

The following are the key lessons learned from the assessment:

- **Evaluations should be performed by an independent party who has no vested interest or stake in the project itself to eliminate potential bias.** An evaluation of a project or a program is essential to discover how well the project or program is able to attain its goals. An independent evaluation by a third party who has no vested interest or stake in the project will eliminate bias in the findings. An independent evaluation can help inform the U.S. DOT or MLIT if their investments were able to achieve the project or program goals; of the lessons that can be used to improve the continued operation of the cooperative system as well as the design of future projects; and of how resources should be applied in the future.

- **More rigorous experimental design is needed to better isolate benefits of cooperative systems or ITS implementations**. The review revealed that most of the evaluation efforts were challenged by their inability to isolate the impacts of the connected vehicle or ITS implementations from those of exogenous factors or competing projects. For example, in Minnesota, U.S., multiple projects with overlapping benefits were underway simultaneously making it difficult to isolate the benefits of the UPA/CRD projects. Secondly, exogenous factors, such as rising gas prices, unemployment, etc., made it difficult to determine the effectiveness of the UPA/CRD projects. A good experimental design can minimize impacts of exogenous or confounding factors. One approach to solving this issue is by identifying control (without) and treatment (with) groups that experience the same or similar exogenous factors.

- **Consistent dollar values should be applied when monetizing benefits**. There are inconsistencies in the valuation of benefits across programs and across projects even within the same national evaluation program. In the U.S., the UPA/CRD San Francisco project used the value of time for travelers and truck drivers from 2000, while the UPA/CRD Minnesota and Atlanta projects used the revised value of time from 2009 ($12.50). The ICM AMS Dallas effort used $12.00 as the value of time, while the ICM AMS San Diego effort used $24.00. Neither of the two efforts used the recommended value of traveler time, which is $12.50 based on the revised valuation of travel time issued by U.S. DOT. Most up to date U.S. DOT guidance on valuation of benefits should be used across all evaluation projects in the U.S. Any deviations and reasons for deviation should be noted in the evaluation plans. A similar approach should also be used in Japan.

- **Acceptance of cooperative systems based on short-term exposures can be misleading.** As cooperative systems are in their infancy, minimal data exist. There is lack of information or behavioral theory regarding how drivers would respond to warnings from cooperative systems, especially if multiple warnings are generated due to detection of multiple threats. Large FOT investments will benefit from comparable investment in data collection, storage, and analytics. Small scale FOTs should be supplemented by additional FOTs, small-scale demonstrations, and/or analytical studies.

- **Longer-term impact of cooperative systems should be examined prior to large scale deployment.** Prior to deploying cooperative systems on a large scale, it is essential to assess the robustness, effectiveness, usability, and acceptance of the systems as tested as well as projected over time and geographic scope, and for varying market adoption rates of application and driver compliance rates. For example, testing of different road side equipment (e.g., ITS Spot units) deployment densities should be examined to assess at what point there is diminishing marginal returns. Such longer-term impacts assessments may necessitate the use of analytical tools or techniques.

# 8 Conclusions and Opportunities for Future Collaboration

## 8.1 Conclusions

The report is an outcome of the U.S.-Japan bi-lateral collaborative research on evaluation tools and methods. The report includes:

- Case studies of cost-benefit evaluations, including performance indicators, and measurement methods, of Intelligent Transportation Systems (ITS) and cooperative systems in the U.S. and Japan
- Comparison and assessment of existing evaluation methods used for evaluating ITS and cooperative systems in the U.S. and Japan
- Consistent glossary of terms for evaluations for use in the U.S. and Japan
- Consistent categorization and organization of performance indicators and measurement methods

## 8.2 Opportunities for Future Collaboration

The following are some opportunities for future collaboration between U.S. and Japan, including:

- Development of consistent methodology for evaluations
- Application of the consistent methodology to evaluate a cooperative system deployment, either in the U.S. or in Japan (or one each in both nations)

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# Appendix: Glossary of Terminology

The U.S. and Japan are increasingly working together to coordinate research activities for the evaluation of connected vehicle and probe data systems. This glossary is a collection of terms that are used to describe components of connected vehicle and probe data systems; evaluation tools and methods that are used to assess the effectiveness of ITS strategies; and performance metrics and indicators. Each term has a definition, a source from where the definition is taken, and the region where the definition is used.

This was developed as a working glossary of terms in 2014. As is evidenced by the glossary below, some terms have multiple, inconsistent definitions which vary not only by nation, but by agency or project. In this report, an attempt has not been made to synthesize common definitions for the terms.

**Table 15: Glossary of Terminology**

| Term | Definition | Source | Region |
|---|---|---|---|
| Agency efficiency | Agency efficiency comprises a set of performance criteria that may be used to monitor such agency practices as service provision, coordination, and the quality of available information. As documented in the a standardized baseline survey completed by transit operators in San Diego and Houston, measures of agency efficiency performance metrics in the context of integrated corridor management (ICM) include:<br>• Effectiveness of pre-defined traffic signal timing plans<br>• Effectiveness of adjustments made to traffic signal timing plans<br>• Quality of pre-defined incident/event response plans<br>• Ability to effectively report transportation conditions and status of assets to other operators, emergency responders, and the media<br>• Effectiveness of inter-agency coordination<br>• Usefulness of real-time information available to operators to support decision-making<br>• Usefulness of information operators provide to travelers for trip-making decisions<br>• Perception of operators relative to intervention in altering recommended responses<br>• Extent of inter-agency coordination of construction and maintenance<br>• Extent of inter-agency coordination during special events | ICM Initative: Demonstration Phase Evaluation Interim Technical Memorandum: Baseline Data Collection | US |
| AMS test bed | Analysis, Modeling, and Simulation (AMS) Testbed is a set of evaluation tools that emulates in a laboratory setting, a real-world network or testbed. | DMA-ATDM AMS report | US |
| Analytical/ Deterministic Tools | Most analytical/deterministic tools implement the procedures of the Highway Capacity Manual (HCM). The HCM procedures are closed-form, macroscopic, deterministic, and static analytical procedures that estimate capacity and performance measures to determine the level of service (e.g., density, speed, and delay). The practitioner inputs the data and the parameters and, after a sequence of analytical steps, the HCM procedures produce a single answer. | Traffic Analysis Toolbox - Vol. II | US |
| Average Vehicle Occupancy (AVO) | The average number of persons per vehicle, including transit vehicles, on the transportation facility or system. | Traffic Analysis Toolbox - Vol. II | US |
| Benefit/Cost | Ratio of annualized, monetized benefits to total costs associated with transportation improvement(s). | Traffic Analysis Toolbox - Vol. II | US |
| BSM | Basic Safety Messages | USDOT ITS-JPO Website | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Buffer Index | The Buffer Index represents the extra time (or time cushion) travelers need to add to their average trip time to ensure an on-time arrival (travel time variability metric). | USDOT FHWA Office of Operations: Travel Time Reliability brochure | US |
| Bus on-time performance | The percentage of bus arrivals that fall within a specified threshold of the scheduled arrival time | UPA - Minnesota | US |
| Bus throughput | The number of buses operating along a given corridor during a given time period. | UPA - Minnesota | US |
| Calibration | Calibration is a mathematical process to identify the global and link specific parameters for driver behavior and vehicle operation that cause the simulation model to best reproduce observed real-world behavior for existing local conditions. Calibration is performed locally by the analyst for each individual application of the simulation model to a real-world road network.<br><br>During the calibration process the modeler varies operational parameter values within acceptable or agreed upon specified ranges until the modeled outputs and observed outputs agree to an acceptable level of accuracy. So that the differences between the modeled and observed data are reduced.<br><br>This process also includes the statistical verification of the model outputs vis à vis the field-measured local conditions. | FHWA TAT team | US |
| | The changing of model parameters relating to the road network to ensure that the interactions of individual vehicles are realistic. | Paramics Microsimulation Consultancy Good Practice Guide | US |
| Capacity | Capacity of a facility is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform sections of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. Capacity reflects a transportation facility’s ability to accommodate a moving stream of people or vehicles. [TAT Vol. III] | HCM, Traffic Analysis Toolbox – Vol. III | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Car Following Model | Driver behavior model that controls how a following vehicle adjusts its speed in relation to the leading vehicle. | Wisconsin VISSIM Guide | US |
| Commercial Vehicle Safety Violations | Number of violations issued by law enforcement based on vehicle weight, size or safety | Traffic Analysis Toolbox - Vol. VI | US |
| Confidence Interval | Confidence intervals are a means of recognizing the inherent variation in microsimulation model results and conveying them to the decision maker in a manner that clearly indicates the reliability of the results. | Traffic Analysis Toolbox - Vol. III | US |
| Confidence Level | Measure of accuracy or variability among samples. | Level of Effort Document | US |
| Congestion Duration | The length of the period of congestion | Traffic Analysis Toolbox - Vol. VI | US |
| Connected Vehicle System | Connected vehicles refer to the ability of vehicles of all types to communicate wirelessly with other vehicles and roadway equipment, such as traffic signals, to support a range of safety, mobility and environmental applications of interest to the public and private sectors. Vehicles include light, heavy and transit vehicles. The concept also extends to compatible aftermarket devices brought into vehicles and to pedestrians, motorcycles, cyclists and transit users carrying compatible devices, which could make these vulnerable users more visible to surrounding traffic. | USDOT ITS-JPO Website | US |
| Cooperative Systems | These are systems that can bring new intelligence for vehicles, roadside systems, operators and individuals, by creating a universally understood communications "language" allowing vehicles and infrastructure to share information and cooperate in an unlimited range of new applications and services. | EU-US Combined Glossary of Terms | US |
| Crashes | Number of crashes on a transportation facility or network | Traffic Analysis Toolbox - Vol. II | US |
| Crash Clearance Time | Time between first recordable awareness of a crash by a responsible agency and time at which the last responder has left the scene | USDOT FHWA Emergency Transportation Operations | US |
| Crash Duration | Crash duration is calculated from the moment the crash obstructs travel until the incident is cleared (expressed in minutes or hours) | Traffic Analysis Toolbox - Vol. II | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Crash Response Time | The period required for a crash to be identified, verified, and for an appropriate responder to alleviate the interruption to traffic to arrive at the scene. | NCHRP | US |
| Delay | The Year 2000 Highway Capacity Manual defines delay as "The additional travel time experienced by a driver, passenger, or pedestrian." Unfortunately the HCM does not define the yardstick against which the "additional travel time" is measured in order to determine delay. So the various microsimulation software define and measure "delay" differently. For some, delay is the difference between the actual travel time for a link and the theoretical travel time at the coded free-flow speed for the link. For others, delay is the difference between the actual link travel time for each vehicle and the theoretical travel time if the vehicle had traversed the link at its desired speed (which can be different than the link free-flow speed). | Caltrans Guide on Simulation | US |
| | Additional travel time experienced by travelers at speeds less than the freeflow (posted) speed (expressed in seconds or minutes). | Traffic Analysis Toolbox - Vol. II | US |
| | The travel time (for all vehicles entering and attempting to enter the system during the analysis period) minus the theoretical travel time at the freeflow speed. This difference is divided by the number of vehicle trips to obtain mean delay per trip. | Traffic Analysis Toolbox - Vol. VI | US |
| Demand | Demand is defined as the number of vehicles and the percentage of vehicles of each type that wish to traverse the study area during the simulation time period. | Traffic Analysis Toolbox - Vol. III | US |
| Demand Forecast | Forecasts of future travel demand are best obtained from a travel demand model. | Traffic Analysis Toolbox - Vol. III | US |
| Density | The number of vehicles on a roadway segment averaged over space (usually expressed in vehicles per mile or vehicles per lane per mile) | Traffic Analysis Toolbox - Vol. II | US |
| | Number of vehicles per lane per period | Traffic Analysis Toolbox - Vol. VI | US |
| Departure Time Changes | Represents changes in the trip start time | Traffic Analysis Toolbox - Vol. II | US |
| Destination changes | Represents changes to travel destinations | Traffic Analysis Toolbox - Vol. II | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Discount Rate | The rate at which predicted cash expenditures (costs) or inflows (benefits) are reduced in future years to reflect the time cost of money. The purpose of the discount rate is to convert future values to present value. | Operations Benefit/Cost Analysis Desk Reference | US |
| Driver Distraction | Frequency of looking out ahead | | JP |
| DSRC | Dedicated Short Range Communications: these provide low-latency data-only V2V and V2I communications for use in applications such as such as Electronic Fee Collection (EFC), crash avoidance, and In-Vehicle Signing.<br><br>The term “DSRC” originally was used to refer to tolling systems at 5.8 GHz. Now the term is also used to refer to DSRC operation at 5.9 GHz under the IEEE 802.11p standard. | EU-US Combined Glossary of Terms | US |
| Dynamic Traffic Assignment (DTA) | A process for assigning vehicle routes in a simulation model based on network conditions. It is an iterative process that converges to a path assignment based on vehicle travel time and delay between origin and destination (O-D) points in the network. While sometimes used in practice to refer to the macro- or mesoscopic traffic assignment in a travel demand model such as VISUM, for the purposes of this document, DTA refers to the microscopic dynamic traffic assignment within VISSIM. | Wisconsin VISSIM Guide | US |
| Emissions | The predicted emissions for each pollutant type on a transportation facility or network | Traffic Analysis Toolbox - Vol. II | US |
| Evacuation clearance time | The combined reaction and travel time for evacuees to leave an area at risk | Traffic Analysis Toolbox - Vol. VI | US |
| Extent of Congestion – Spatial | Miles of roadway within a predefined area and time period for which average travel times are 30% longer than unconstrained (free flow) travel times. | NCHRP | US |
| Extent of Congestion – Temporal | The time duration during which more than 20% of the roadway sections in a predefined area are congested as defined by the “Extent of Congestion – Spatial” performance measure. | NCHRP | US |
| External Factors | In the context of Logic Modes, external factors are identified that might positively or negatively influence the outcomes of the program | ICM National Framework | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Field Operational Test (FOT) | A real-world test activity over an extended period of time conducted in real traffic not using professional test drivers and using near production systems. The intent is to get empirical data on impacts, user acceptance, and technical performance, as well as an understanding of unintended consequences. | EU-US Combined Glossary of Terms | US |
| Free-Flow Speed | The mean speed of traffic at low flow conditions, where the flow rate has no significant effect on actual vehicle speeds. This can be, but is not usually, the speed limit. | Caltrans Guide on Simulation | US |
| | The free-flow speed is defined as the minimum of the maximum safe speed or the analyst coded speed limit. Note that turning vehicles at an intersection would have a lower maximum safe speed than through vehicles. | TAT Vol. VI | US |
| | The mean speed at which traffic would travel if there were no congestion or any other adverse condition to lower speed. | Wisconsin VISSIM Guide | US |
| | Free flow speeds are those observed from vehicles whose operations are unimpeded by traffic control devices (e.g., ramp meters) or by other vehicles in the traffic stream. | http://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa10001/), NCHRP | US |
| Fuel Consumption | The fuel consumption rate associated with the use of a transportation facility or network | Traffic Analysis Toolbox - Vol. II | US |
| Gap | The time or distance between the tail end of the leading vehicle and the front end of the following vehicle. | Caltrans Guide on Simulation | US |
| | The time or distance between the back end of a leading vehicle and the front end of the following vehicle. | Wisconsin VISSIM Guide | US |
| HOT Lane Frequency of Use | The count of trips in HOT lanes during each analysis period for each unique transponder | UPA - Minnesota | US |
| Incident | A vehicle breakdown, accident, or other event that causes full or partial obstruction of vehicle movements in a lane during the simulation period. | Caltrans Guide on Simulation | US |
| | A traffic interruption caused by a crash or other unscheduled event | Traffic Analysis Toolbox - Vol. VI | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Incident Clearance Time | Time between first recordable awareness of incident by a responsible agency and time at which the last responder has left the scene. | USDOT FHWA Emergency Transportation Operations | US |
| Incident Duration | Incident duration includes all crashes and vehicle incidents, such as running out of gas and mechanical problems. It is calculated from the moment the vehicle or object obstructs travel until the incident is cleared (expressed in minutes or hours) | Traffic Analysis Toolbox - Vol. II | US |
| Incident Response Time | The period required for an incident to be identified, verified, and for an appropriate action to alleviate the interruption to traffic to arrive at the scene. | NCHRP; Traffic Analysis Toolbox - Vol. VI | US |
| Induced/ Foregone Demand | Estimates new trips (induced demand) or foregone (cancelled or skipped) trips resulting from the implementation of traffic management strategies | Traffic Analysis Toolbox - Vol. II | US |
| Inputs | In the context of Logic Models, inputs represent investments (hardware, software, infrastructure, staff hires, training, development or revision of policies and procedures, memoranda of understanding, etc.) | ICM National Framework | US |
| Level of Service (LOS) | Qualitative measure describing operational conditions within a traffic stream based on service measures, such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience. Ranges from LOS A (best) to LOS F (worst). | Traffic Analysis Toolbox - Vol. II, Vol VI. | US |
| Link | One-directional segments of surface streets or freeways. Links represent the length of the segment and usually contain data on the geometric characteristics of the road or highway between the nodes. Ideally, a link represents a roadway segment with uniform geometry and traffic operation conditions. | Traffic Analysis Toolbox - Vol. III | US |
| Link-Node Diagram | The link-node diagram is the blueprint for constructing the microsimulation model. The diagram identifies which streets and highways will be included in the model and how they will be represented. | Traffic Analysis Toolbox - Vol. III | US |
| Logic Model | A logic model describes the relationship between program resources, planned activities, and expected results through a series of statements that link program components (inputs, activities, outputs and outcomes) in a chain of causality. The logic model provides a conceptual framework for evaluating a program, including expectations, organization of the work, and evaluation. The model explicitly recognizes that the ultimate successes or shortcomings of a technology deployment are the end results of a long series of interdependent events and conditions (causes and effects), and stresses a step-wise approach in which each link in the cause-effect chain is investigated in the evaluation. | ICM National Framework | US |

| Term | Definition | Source | Region |
| --- | --- | --- | --- |
| Macroscopic Simulation Models | Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic simulation models operate on the basis of aggregate speed/volume and demand/capacity relationships. | Traffic Analysis Toolbox - Vol. II | US |
| Mean corridor peak-period travel times | The average travel time through the length of the entire corridor by peak period (reported separately for managed vs. general purpose lanes). | UPA - Minnesota | US |
| Mean peak-period flow rates | A normalized measure of how many vehicles can move through a cross section on a per-lane basis and can be directly related to the level of congestion experienced at the cross sections. Typically expressed in vehicles per hour per lane. | UPA - Minnesota | US |
| Mean peak-period travel speeds | An average travel speed through the entire length of the corridor by peak period. | UPA - Minnesota | US |
| Measure of Effectiveness (MOEs) | MOEs are the system performance statistics that best characterize the degree to which a particular alternative meets the project objectives. | Traffic Analysis Toolbox - Vol. III | US |
| Median peak-period per-lane vehicle throughput | The median number of vehicles traveling in a lane during the peak period in the peak direction. | UPA - Minnesota | US |
| Median Peak-Period Vehicle Miles Traveled (VMT) | The median number of VMT by section during the peak-period | UPA - Minnesota | US |
| Mesoscopic Simulation Model | Mesoscopic models combine the properties of both microscopic and macroscopic simulation models. Mesoscopic model travel prediction takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than microsimulation tools, but are superior to the typical planning analysis techniques. | Traffic Analysis Toolbox - Vol. II | US |
| Message throughput | The number of messages (successfully) delivered per unit time. It depends on several network parameters (e.g., queuing, two-way latency, available bandwidth, radio channel quality and potential retransmissions). | EU-US Combined Glossary of Terms | EU |

| Term | Definition | Source | Region |
|---|---|---|---|
| Microscopic Simulation Model | Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals and are tracked through the network over a brief time intervals. The primary means of calibrating and validating microscopic simulation models are through the adjustment of driver sensitivity factors. | Traffic Analysis Toolbox - Vol. II | US |
| | These models simulate individual vehicle-to-vehicle interactions and traffic control strategies. DTA applications in microscopic models provide the most complex analysis of all the model types. | DTA Guide | US |
| | Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. | Traffic Analysis Toolbox - Vol. II | US |
| | Modeling of individual vehicle movements on a second or sub-second basis for the purpose of assessing the traffic performance of a transportation network. | Wisconsin VISSIM Guide | US |
| Missed detection | Missed detection indicates the situation in which a collision avoidance system fails to detect a thread which the system is designed to detect. | EU-US Combined Glossary of Terms | EU |
| Modal Split | The percentage of travelers using each travel mode (SOV, HOV, transit, bicycle, pedestrian, etc.) | Traffic Analysis Toolbox - Vol. II | US |
| Mode shifts | Mode shift captures changes regarding the selection of travel modes | Traffic Analysis Toolbox - Vol. II | US |
| Model | Specific combination of modeling software and analyst-developed inputs/parameters for a specific application. A single model may be applied to the same study area for several time periods and several existing and future improvement alternatives. | Traffic Analysis Toolbox - Vol. III | US |
| Network | The physical representation of the roads: nodes, links and associated features, but not including assigned trips. | Paramics Microsimulation Consultancy Good Practice Guide | US |
| Node | Nodes are the intersection of two or more links. Nodes are usually placed in the model using x-y coordinates and they can be at a place that represents an intersection or a location where there is a change in the link geometry. | Traffic Analysis Toolbox - Vol. III | US |

| Term | Definition | Source | Region |
| --- | --- | --- | --- |
| Noise | The sound level produced by traffic (expressed in decibels) | Traffic Analysis Toolbox - Vol. II | US |
| Nomadic Device | A nomadic device is a device that can be carried by a single person throughout a complete door-to-door trip, including pedestrian, transit and private vehicle modes. The device function can vary throughout the trip. | DMA-ATDM AMS report | US |
| Number of incidents | Number of traffic interruptions caused by a crash or other unscheduled event. [TAT Vol VI] | Traffic Analysis Toolbox – Vol. VI, NCHRP | US |
| OBE | On-Board Equipment – a piece of ITS related hardware that is located in a vehicle to collect data from the vehicle, and/or provide an interface through which ITS services can be provided, e.g. tolls, navigation, trip planning, travel information. If there is only one piece of equipment or several pieces of equipment are packaged into a single physical entity, then it is called an On-Board Unit (OBU). | EU-US Combined Glossary of Terms | US |
| Outcomes | In the context of Logic Models, outcomes describe the short-term, medium-term, and long-term impacts of the investments (e.g., decrease in hard-braking →decrease in emissions → reduction in pollution-related illnesses) | ICM National Framework | US |
| Outputs | In the context of Logic Models, outputs describe how investments are utilized, the capabilities they provide, and how those capabilities are used (e.g., outputs that reflect operators' utilization of the investments to provide road weather advisories; direct outputs of technology systems, such as the improvement in data collected through new or enhanced sensors) | ICM National Framework | US |
| Oversaturation | If the observed density is greater than the density at capacity, then the freeway is considered to be oversaturated or in "breakdown" condition. | Traffic Analysis Toolbox - Vol. VI | US |
| Packet error rate | The number of incorrectly transferred data packets divided by the number of transferred packets. A packet is assumed to be incorrect if at least one bit in it is incorrect. | EU-US Combined Glossary of Terms | EU |
| Park-and-ride lot daily usage | The average number of parking spaces occupied at a park-and-ride lot (weekdays). | UPA - Minnesota | US |
| Percent of System Congested | The percent of miles congested (usually defined based on LOS E or F) | Traffic Analysis Toolbox - Vol. VI | US |

| Term | Definition | Source | Region |
| --- | --- | --- | --- |
| Percent of Travel Congested | The percent of vehicle miles or person miles traveled in congested conditions | Traffic Analysis Toolbox - Vol. VI | US |
| Performance measure | A *performance measure* is directly associated with a particular goal and reflects measurable evidence that can be used to determine progress toward that goal. This evidence can be quantitative in nature (such as the measurement of customer travel times) or qualitative (such as the measurement of customer satisfaction and customer perceptions). | INFLO report | US |
| Pilot Deployment | A real-world test activity over an extended period of time conducted in real traffic not using professional test drivers and using near production systems. The intent is to get empirical data on impacts, user acceptance, and technical performance, as well as an understanding of unintended consequences. Pilot deployments are identical to FOTs, except that at the end of the pilot, the system becomes part of the normal operating practice, while for an FOT, the system is dismantled. | | US |
| Planning Time Index | Represents how much total time a traveler should allow to ensure on-time arrival. The planning time index shows the total travel time that is necessary to ensure on-time arrival. | USDOT FHWA Office of Operations: Travel Time Reliability brochure | US |
| Platoon | A vehicle is defined to be in a platoon if it is following another vehicle by 3 seconds or less. | Traffic Analysis Toolbox - Vol. VI | US |
| Probe Data | Probe data are data generated by vehicles (light, transit, and freight vehicles) about their current position, motion, and timestamp. Probe data also include additional data elements provided by vehicles that have added intelligence to detect traction information, break status, hard breaking, flat tire, activation of emergency lights, anti-lock brake status, air bag deployment status, windshield wiper status, etc. Probe data from vehicles may be generated by devices integrated with the vehicles' computers, or nomadic devices brought into the vehicles. | US-Japan Collaborative Research on Probe Data: Assessment Report | US & Japan |

| Term | Definition | Source | Region |
| --- | --- | --- | --- |
| Queue | According to HCM (Appendix A, page 16-90), a queue is "a line of vehicles [or bicycles or persons] waiting to be served by the system in which the flow rate from the front of the queue determines the average speed within the queue. Slowly moving vehicles…joining the rear of the queue are…considered part of the queue. The internal queue dynamics can involve starts and stops..." A vehicle is considered as queued "when it approaches within one car length of a stopped vehicle and is itself about to stop." | Highway Capacity Manual, 2000 | US |
| | Vehicles waiting to be served by the system (expressed in distance or number of vehicles). | Traffic Analysis Toolbox - Vol. II, Traffic Analysis Toolbox - Vol. VI | US |
| Queue Length | Number of vehicles in queued state | | US |
| Reliable Throughput | Reliable throughput is defined as traveler trips or traveler miles delivered reliably by the system. | DMA-ATDM AMS report | US |
| Ridership | The number of passengers on the transit system being evaluated | Traffic Analysis Toolbox - Vol. II | US |
| Roadway Clearance Time | The time between first recordable awareness of incident by a responsible agency and first confirmation that all lanes are available for traffic flow. | USDOT FHWA Emergency Transportation Operations | US |
| Route Diversion | Captures changes in travel routes, including pre-trip route diversion and enroute diversion | Traffic Analysis Toolbox - Vol. II | US |
| | Captures changes in travel routes, including pre-trip route | Traffic Analysis Toolbox - Vol. II | US |
| RSE | Road Side Equipment – a piece of ITS related hardware that is located at the side of the road to exchange data with vehicles in its locality and in some instances provide an interface through which travelers can access ITS related services, e.g. Public Transport schedules. If there is only one piece of equipment or several pieces of equipment are packaged into a single physical entity, then it is called a Road Side Unit (RSU). | EU-US Combined Glossary of Terms | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Sample Size | This is the size or the number of observations in a sample, which is used the make inferences about the population being studied. | Combination of multiple definitions | US |
| Saturation Flow Rate | Saturation flow rate is defined as “the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost times are experienced, in vehicles per hour or vehicles per hour per lane.”(HCM 2000) The saturation flow rate should be measured (using procedures specified in the HCM) at all signalized intersections that are operating at or more than 90 percent of their existing capacity. | Traffic Analysis Toolbox - Vol. III | US |
| Security for highway and transit | The number of violations issued by law enforcement for acts of violence against travelers | Traffic Analysis Toolbox - Vol. VI | US |
| Sensitivity Analysis | A sensitivity analysis is a targeted assessment of the reliability of the microsimulation results, given the uncertainty in the input or assumptions. The analyst identifies certain input or assumptions about which there is some uncertainty and varies them to see what their impact might be on the microsimulation results. | Traffic Analysis Toolbox - Vol. III | US |
| Shockwave | Shockwaves can be defined as transition zones between two traffic states (e.g., from free-flow to congestion) that move through a traffic environment like a propagating wave. Shockwaves are typically caused by a change in capacity on the roadways (a 4 lane road drops to 3), an incident, a traffic signal on an arterial, or a merge on freeway. Speeds of the vehicles moving through the bottleneck will of course be reduced, but the drop in speed will cascade upstream as following vehicles also have to decelerate. | INFLO report | US |
| Shockwave Propagation | Traffic shockwaves typically move upstream (or “backwards”) relative to a wave front that marks the transition between the two states, through the traffic stream. The direction and speed of propagation of a shockwave depends on the respective differences in flow and density associated with the two states (i.e., $(Q_2-Q_1)/(K_2-K_1)$, where $Q_1$ and $Q_2$ denote flows associated with states 1 and 2, and $K_1$ and $K_2$ the corresponding densities). | INFLO report | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Sketch Planning Tools | Sketch-planning methodologies and tools produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation improvements. Sketch-planning tools perform some or all of the functions of other analytical tools using simplified analytical techniques and highly aggregated data. Such techniques are primarily used to prepare preliminary budgets and proposals, and are not considered a substitute for the detailed engineering analysis often needed later in the implementation process. Traffic volume to capacity ratios are often used in congestion analyses. | Traffic Analysis Toolbox - Vol. II | US |
| Space mean speed | Arithmetic mean of the speed of those vehicles occupying a given length of road at a given instant. It is also defined as the harmonic mean of speeds passing a point over a period of time. | U. Idaho Traffic Flow Theory Glossary | US |
| Speed | Rate of motion (expressed in distance per unit of time). The mean speed for a road segment can be estimated by measuring travel time and dividing the segment length by the mean travel time. | Traffic Analysis Toolbox - Vol. II, Traffic Analysis Toolbox - Vol. VI | US |
| Statistical Power Analysis | Power analysis can be conducted *a priori* (before) or post-hoc (after). *A priori* power analysis is used to estimate sufficient sample sizes to achieve adequate statistical power. A post-hoc power analysis uses the sample size and effect size to determine what the statistical power was in the study. | Statistical Power Analysis | US |
| Stochastic Tools | Stochastic modeling is the counterpart to deterministic modeling and introduces randomness. There is some indeterminacy in the future evolution of the analysis, as described by probability distributions. These tools can evaluate the evolution of traffic congestion problems on transportation systems. By dividing the analysis period into time slices, a simulation model can evaluate the buildup, dissipation, and duration of traffic congestion over time. Simulation models, by evaluating entire systems of facilities, can pinpoint the interference that occurs when congestion builds up at one location before it impacts other locations. Also, traffic simulators can model the variability in driver/vehicle characteristics.<br>Examples of stochastic models are macroscopic models, mesoscopic models, and microscopic models. | Traffic Analysis Toolbox – Vol. X | US |
| Stops | The number of stops experienced by the section and/or corridor (based on some minimum travel speed) | Traffic Analysis Toolbox - Vol. II | US |
| | The number of times a vehicle stops while traveling | Traffic Analysis Toolbox - Vol. VI | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| Surveys (Questionnaires) | These are a series of questions aimed at gathering information from respondents to make statistical inferences about the population being studied. | Combination of multiple definitions | US |
| Throughput | Throughput is defined as the number of distinct vehicles (or people) able to enter or exit the system during the analysis period | Traffic Analysis Toolbox - Vol. VI | US |
| | Number of persons including vehicle occupants, pedestrians, and bicyclists traversing a roadway section in one direction per unit time. May also be defined as the number of persons traversing a screen line in one direction per unit time. | NCHRP | US |
| | Number of vehicles traversing a roadway section in one direction per unit time. May also be defined as the number of vehicles traversing a screen line in one direction per unit time. | NCHRP | US |
| Time mean speed | Arithmetic mean of the speed of vehicles passing a point during a given time interval. | U. Idaho Traffic Flow Theory Glossary | US |
| Toll Revenue | Dollars generated from tolls | Traffic Analysis Toolbox - Vol. VI | US |
| Total annual regional transit ridership | The total number of trips taken on all transit services in the region. | UPA - Minnesota | US |
| Traffic Signal Optimization Tools | Traffic optimization tool methodologies are based off of HCM procedures and are primarily designed to develop optimal signal phasings and timing plans for isolated signal intersection, arterial streets, or signal networks. This may include capacity calculations; cycle length; splits optimization, including left turns; and coordination/offset plans. | Traffic Analysis Toolbox - Vol. II | US |
| Travel Costs | Value of driver's time during a trip and any expenses incurred | Traffic Analysis Toolbox - Vol. VI | US |
| Travel Demand Model | Travel demand models are mathematical models that forecast future travel demand based on current conditions and future projections of household and employment characteristics. Travel demand models only have limited capabilities to accurately estimate changes in operational characteristics (such as speed, delay, and queuing) resulting from implementation of ITS/operational strategies. These inadequacies generally occur because of the poor representation of the dynamic nature of traffic in travel demand models. | Traffic Analysis Toolbox - Vol. II | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| | Travel demand models have specific analytical capabilities, such as the prediction of travel demand and the consideration of destination choice, mode choice, time-of-day travel choice, and route choice, and the representation of traffic flow in the highway network. These are mathematical models that forecast future travel demand based on current conditions, and future projections of household and employment characteristics. | Traffic Analysis Toolbox - Vols. I & II | US |
| Travel Distance | Extent of space between the trip origin and the destination, measured along a vehicular route. | Traffic Analysis Toolbox - Vol. II | US |
| Travel Time | Distance divided by speed | Traffic Analysis Toolbox - Vol. VI | US |
| | Average time spent by vehicles traversing a facility, including control delay, in seconds or minutes per vehicle. | Traffic Analysis Toolbox - Vol. II | US |
| | The average time required to traverse a section of roadway or other facility in a single direction. | NCHRP | US |
| Travel Time Index | This represents the additional time required to make a trip during peak periods. The additional time required is a result of increased traffic volumes on the roadway and the additional delay caused by crashes, poor weather, special events, or other nonrecurring incidents. | | US |
| Travel Time Reliability | Quantification of the unexpected, non-recurring delay associated with excess travel demand, incidents, weather or special events. There are several methods for predicting reliability or variability in travel times. Reliability of travel time is a significant benefit to travelers as individuals are better able to predict their travel time and budget less time for their trip. | Traffic Analysis Toolbox - Vol. II | US |
| | Travel time reliability is a quantification of the unexpected non-recurring delay associated with excess travel demand, incidents, weather, or special events. There are several methods for predicting reliability or variability in travel times. Reliability of travel time is a significant benefit to travelers as individuals are better able to predict their travel time and budget less time for their trip. | Traffic Analysis Toolbox - Vol. II | US |
| Travel Time Savings (bus) | The amount of time (in seconds) of travel time per bus run saved from pre-deployment to post-deployment | UPA - Minnesota | US |
| Traveler Response | Includes route diversion, departure time choice, mode shift, destination choice, and induced/foregone demand. | Traffic Analysis Toolbox - Vol. II | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| User Satisfaction | This is a measure or indicator of how products or services meet or exceed the user's (customer's) expectations. | Combination of multiple definitions | US |
| Validation | Validation is used in the literature for two distinct phases of model acceptance testing. During the software development phase, validation is one or more tests of the ability of the theoretical equations and rules in the simulation model to imitate real-world driver behavior. Validation during this phase is performed by researchers during the development of micro-simulation models and their associated software. Later, when the analyst is coding a specific local network using the software, validation is the step that follows model calibration. Specific components of the coded model for the local network are first calibrated against a detailed set of field date. The entire coded model is then validated against more global data for the local network during the validation step. | Caltrans Guide on Simulation | US |
| V2I | Vehicle to Infrastructure communications | EU-US Combined Glossary of Terms | US |
| V2V | Vehicle to Vehicle communications | EU-US Combined Glossary of Terms | US |
| Vehicle Occupancy | The number of persons per vehicle | Traffic Analysis Toolbox - Vol. VI | US |
| Vehicle-Miles of Travel (VMT) or Person-Miles of Travel (PMT) | The total distance travelled by all vehicles or persons on a transportation facility or network during a specified period of time (expressed in hours) | Traffic Analysis Toolbox - Vol. II, UPA Minnesota | US |
| | Volume times length | Traffic Analysis Toolbox - Vol. VI | US |
| Volume | The number of persons or vehicles passing a point on a roadway during some time interval (expressed in vehicles, bicycles, or persons per hour). It is expressed as the annual average daily traffic, peak-hour traffic or peak-period traffic. | Traffic Analysis Toolbox - Vol. II; Vol. VI | US |
| Volume-to-Capacity (V/C) Ratio | The ratio of flow rate to capacity for a transportation facility | Traffic Analysis Toolbox - Vols. II & VI | US |
| Weather-related traffic incidents | A traffic interruption caused by inclement weather | Traffic Analysis Toolbox - Vol. VI | US |

| Term | Definition | Source | Region |
|---|---|---|---|
| 95th (or 90th) percentile travel time | Estimates how bad delay will be on specific routes during the heaviest travel days. The one or two bad days each month mark the 95th or 90th percentile, respectively. | USDOT FHWA Office of Operations: Travel Time Reliability brochure | US |
| | The reported travel time for the 95th percentile vehicles through the length of the entire corridor (measure of travel time variability). | UPA - Minnesota | US |

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