Dynamic Mobility Applications

Program Evaluation

National-Level Impacts and Costs Estimation

www.its.dot.gov/index.htm

Final Report — July 2016
FHWA-JPO-16-419

U.S. Department of Transportation

Produced by Booz Allen Hamilton for the

Intelligent Transportation Systems Joint Program Office

Office of the Assistant Secretary for Research and Technology

U.S. Department of Transportation

Notice

Technical Report Documentation Page

1. Report No. FHWA-JPO-16-419	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Dynamic Mobility Applications, Program Evaluation National-Level Impacts and Costs Estimation		5. Report Date July 2016 6. Performing Organization Code
7. Author(s) Gustave Cordahi, Mahsa Ettefagh, Sudeeksha Murari		8. Performing Organization Report No.
9. Performing Organization Name And Address Booz Allen Hamilton 8283 Greensboro Drive McLean, Virginia 22102		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-11-D-00019
12. Sponsoring Agency Name and Address U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office 1200 New Jersey Ave SE Washington, DC 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Walter During, Government Task Manager

16. Abstract

The vision of the Dynamic Mobility Applications (DMA) program is to expedite the development, testing, and deployment of innovative mobility applications that maximize system productivity and enhance mobility of individuals within the surface transportation system. The DMA program has the following objectives:

- Develop mobility applications that use frequently collected and rapidly disseminated data drawn from connected vehicles, travelers, and infrastructure.
- Assess mobility applications that improve the capability of the transportation system to provide safe, reliable, and efficient movement of goods and people.
- Identify mobility applications (for possible future investment) that have the potential to improve the performance of dynamic decision making by both system managers and users.
- Accelerate the development, commercialization, and deployment of mobility applications through collaboration with the public, private, and academic community.
- Position the federal government as a technology steward in transforming transportation through connectivity linking travelers, vehicles, and infrastructure.

As part of the DMA program evaluation, this report assesses the national-level impacts and costs of a deployment of the DMA applications based on impact assessment (IA) efforts that were conducted for the various DMA bundles. The bundles include Intelligent Network Flow Optimization (INFLO), Multi-Modal Intelligent Traffic Signal System (MMITSS), Integrated Dynamic Transit Operations (IDTO), Freight Advanced Traveler Information System (FRATIS), Response, Emergency Staging, Communications, Uniform Management and Evacuation (R.E.S.C.U.M.E.), and Enable Advanced Traveler Information System (ATIS).

17. Key Words Applications, Benefits, Connected Vehicles, Costs, Estimation, Extrapolation, Impacts, Mobility	18. Distribution Statement No restrictions

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 104	22. Price

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

Acknowledgements

The DMA support team, including the government leads for all the DMA bundles, and the DMA program support contractors worked collaboratively to develop an approach to conduct the program evaluation of the DMA application bundles, including the assessment of the national impacts and associated costs.

Table of Contents

List of Tables

List of Figures

Executive Summary

The Dynamic Mobility Applications (DMA) program was initiated by the U.S. Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO) to create applications that fully leverage frequently collected and rapidly disseminated multi-source data. This data is gathered from connected travelers, vehicles, and infrastructure to increase efficiency and improve individual mobility while reducing negative environmental impacts and safety risks. The goals of the program are to:

- Develop mobility applications that use frequently collected and rapidly disseminated data drawn from connected vehicles (CVs), travelers, and infrastructure
- Assess mobility applications that improve the capability of the transportation system to provide safe, reliable, and efficient movement of goods and people
- Identify mobility applications (for possible future investment) that have the potential to improve the performance of dynamic decision making by both system managers and users
- Accelerate the development, commercialization, and deployment of mobility applications through collaboration with public, private, and academic communities
- Position the federal government as a technology steward in transforming transportation through connectivity, linking travelers, vehicles, and infrastructure.

In order to achieve its goals, the DMA program sponsored the development, prototyping, and assessment of 17 DMA applications divided into 6 bundles. The program further developed an Open Source Application Development Portal (OSADP) to facilitate application sharing, and an Analysis Modeling and Simulation (AMS) testbed to assess the impacts of single and multiple application scenarios. Table 1 lists the various DMA bundles and their associated applications.

Table 1. DMA Bundles and Applications

ASSOCIATED DMA BUNDLE	DMA APPLICATION
Intelligent Network Flow Optimization (INFLO)	Queue Warning (Q-WARN)
	Dynamic Speed Harmonization (SPD-HARM)
Multi-Modal Intelligent Traffic Signal System (MMITSS)	Intelligent Traffic Signal System (I-SIG)
	Transit Signal Priority (TSP)
	Mobile Accessible Pedestrian Signal System (PED-SIG)
	Emergency Vehicle Preemption (PREEMPT)
	Freight Signal Priority (FSP)
	Connection Protection (T-CONNECT)
	Dynamic Transit Operations (T-DISP)

ASSOCIATED DMA BUNDLE	DMA APPLICATION
Integrated Dynamic Transit Operations (IDTO)	Dynamic Ridesharing (D-RIDE)
Freight Advanced Traveler Information System (FRATIS)	Freight Real-Time Traveler Information with Performance Monitoring (F-ATIS)
	Drayage Optimization (DR-OPT)
	Freight Dynamic Route Guidance (F-DRG)
Response, Emergency Staging, Communications, Uniform Management and Evacuation (R.E.S.C.U.M.E.)	Emergency Communications and Evacuation (EVAC)
	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP- STG)
	Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
Enable Advanced Traveler Information System (EnableATIS)	Multimodal Real-Time Traveler Information (ATIS)
	Smart Park-and-Ride (S-PARK)
	Universal Map Application (T-MAP)
	Real-Time Route-Specific Weather Information (WX-INFO)

Source: Dynamic Mobility Applications (DMA), URL: http://www.its.dot.gov/dma/, accessed on June 2016

The objective of this task is to:

- Integrate findings from the impacts assessment (IA) efforts for each bundle
- Extrapolate national-level impacts and costs of DMA applications over a time frame reflective of a staged nation-wide application deployment.

Under this effort, the mobility impacts of each bundle are estimated exclusive of their interaction with other bundles.

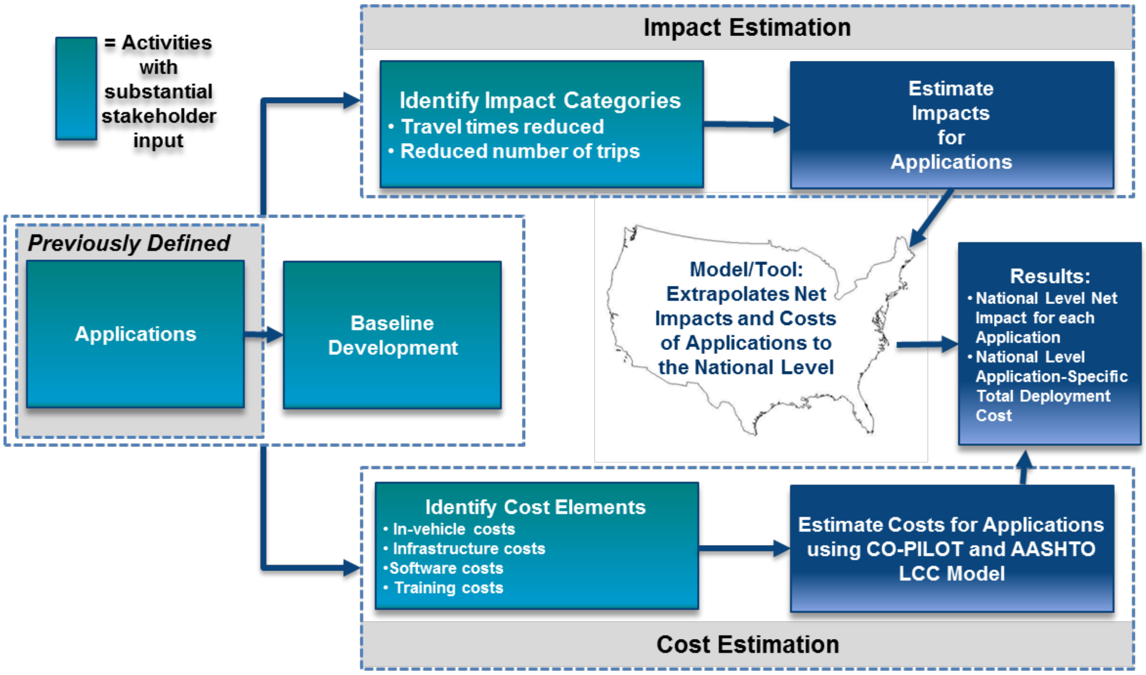
This evaluation's process consists of developing CV deployment assumptions and a baseline. Then, after the assumptions and evaluation framework are vetted by the project team, the DMA applications' national-level impacts and costs are assessed.

Evaluation Approach

Overall Approach: The overall adopted methodology is illustrated in Figure 1. The development of the approach was a collaborative process to ensure consensus on baseline assumptions, benefit categories, and cost components. The approach and assumptions were vetted by the ITS JPO DMA program evaluation support team.

The evaluation was conducted in two parallel phases, one for impacts estimation and the other for application-specific cost estimation. The baseline development phase preceded the benefits and cost estimation phase. The baseline data was used to extrapolate the impacts and costs on a national level and over the duration of the analysis based on the forecasted application deployment rates.

Figure 1. National-Level Impacts and Costs Estimation Approach



Source: Booz Allen Hamilton, July 2016

Key Assumptions: Multiple assumptions affected the results of the analysis. The overall analysis assumptions are:

- The analysis period extends between years 2021 and 2060. The CV deployment during this period is according to the reference deployment curves and application deployment curves, provided by the National Highway Traffic Safety Administration (NHTSA). The application deployment rates for the safety applications were provided. These are estimated as a percentage of the dedicated short range communications (DSRC) equipped vehicles deployment rates. The least aggressive estimate of the application deployment rates is used in the extrapolation model.
- The market penetration rates assume a compliance rate of 100% for all applications. This is in line with the assumptions of the various bundle IA efforts that use an integrated adoption-compliance rate as the discrete "market penetration" rate. A consequence of this approach is that the estimated impacts and costs may be an overestimation. This assumption was made due to the lack of data on the adoption of similar technologies on a large scale.

The key impacts estimation assumptions include:

- The benefits are assessed using results from the IA projects under the DMA program. Some results from single-application scenarios of the AMS testbeds project are also used to fill gaps in the absence of quantitative IA results for some of the bundles, including FRATIS and EnableATIS.

- The primary mobility measure used to assess the national mobility impacts is travel time savings. Travel time reliability improvements were not included in the analysis.
- Safety or environmental benefits were not assessed as part of the quantitative analysis. In some cases, the safety benefits may result in tertiary mobility benefits. These tertiary mobility benefits are noted but not used to estimate costs or impacts. For example, Q-WARN may result in safety benefits by reducing crashes, which can further improve mobility. The indirect mobility benefits of Q-WARN were not considered in the analysis.
- The benefits and costs were only assessed for the applications that were assessed by the IA contractors. These did not cover all of the defined DMA applications.
- The results presented are based on incremental costs and mobility benefits.
- The results presented are for a case of nationwide deployment.
- Applications were evaluated individually; synergies between multiple applications were *not* assessed in this analysis.

The key costs estimation assumptions include:

- Cost breakdown structure (CBS), unit costs, operations and maintenance (O&M) costs, and useful life of each cost element for each application were based on the American Association of State Highway and Transportation Officials (AASHTO) Vehicle to Infrastructure (V2I) Life Cycle Cost (LCC) estimation model and the Cost Overview for Planning Ideas & Logical Organization Tool (CO-PILOT).
- All assumptions for the cost model were made consistent with the AASHTO V2I Life Cycle Cost estimation model.
- The NHTSA deployment curves and national level data were used as volume drivers/multipliers to extrapolate the unit costs to the nationwide application-specific total costs.
- Three types of results are included in the report: i) infrastructure costs (in Appendix C), ii) application-specific costs with no cost sharing (in Appendix B), and iii) application-specific costs considering some cost sharing opportunities (in the body of the report).

The variables that affect the extent of the impacts and/or costs are:

- Application deployment rate—as mentioned earlier, percent of the DSRC-equipped vehicles deployment rates are provided by NHTSA.
- RSU deployment rate—The RSU deployment rates are also assumed the same as the OBU deployment rates provided by NHTSA.
- Value of time (VoT) projection—The VoT is a significant factor in the baseline scenario. The value is used to quantify the time savings for benefit estimation.
- Growth of the volume drivers – The volume drivers used for the benefits estimation are primarily vehicle miles traveled (VMT) by functional system for all bundles except R.E.S.C.U.M.E. The number of incidents is the volume driver for the R.E.S.C.U.M.E.

applications. The growth of the volume drivers over years affects the benefits estimated.

Baseline Development: A baseline scenario with projections of vehicle and transportation infrastructure (e.g., traffic signals) and behavior (e.g., public transit ridership) is developed to evaluate the *world without DMA* through 2060 for the entire United States. The baseline scenario includes assumptions about the deployment of OBU, RSU, and applications. However, these applications are assumed to be used as support only for safety, environment, and security system management goals, and excludes mobility benefits. In addition, there are a number of other factors that will influence the future impacts of applications, including VMT and the number of incidents. These are included in the baseline. Thus, the baseline scenario is used to measure the relative performance of the individual applications to reduce delays and improve mobility. The baseline scenario for cost estimation is developed based on the United States without any deployment of the DMA applications through 2016.

Benefit Estimation: In line with the IA analyses, this national mobility impacts estimation assesses mobility benefits. Mobility benefits are assessed as direct savings in travel time. The benefit values are obtained from the various IA studies of DMA applications. The values are normalized to a unit basis depending on the type of application (e.g., travel time saved per VMT). The various IA reports' inconsistencies in benefit estimates were noted and are documented in this report.

Cost Estimation: This report consists of a detailed description of the methodology and sources used to evaluate cost elements and the total additional costs associated with national level deployment of each DMA application. The cost estimation process is conducted using the AASHTO V2I Life Cycle Cost estimation model. The AASHTO V2I LCC outputs itemized unit and installation costs, annual O&M costs, and replacement intervals for the cost elements associated with each application.

National Extrapolation: This analysis consists of: (1) estimating unit benefits and unit costs for each application; and (2) developing the baseline for providing basic information for extrapolating the results to the nation. A detailed description of the approach to extrapolate the unit costs of the individual cost elements to the national level, using volume drivers and NHTSA deployment rates, is documented in this report.

Results/Key Findings

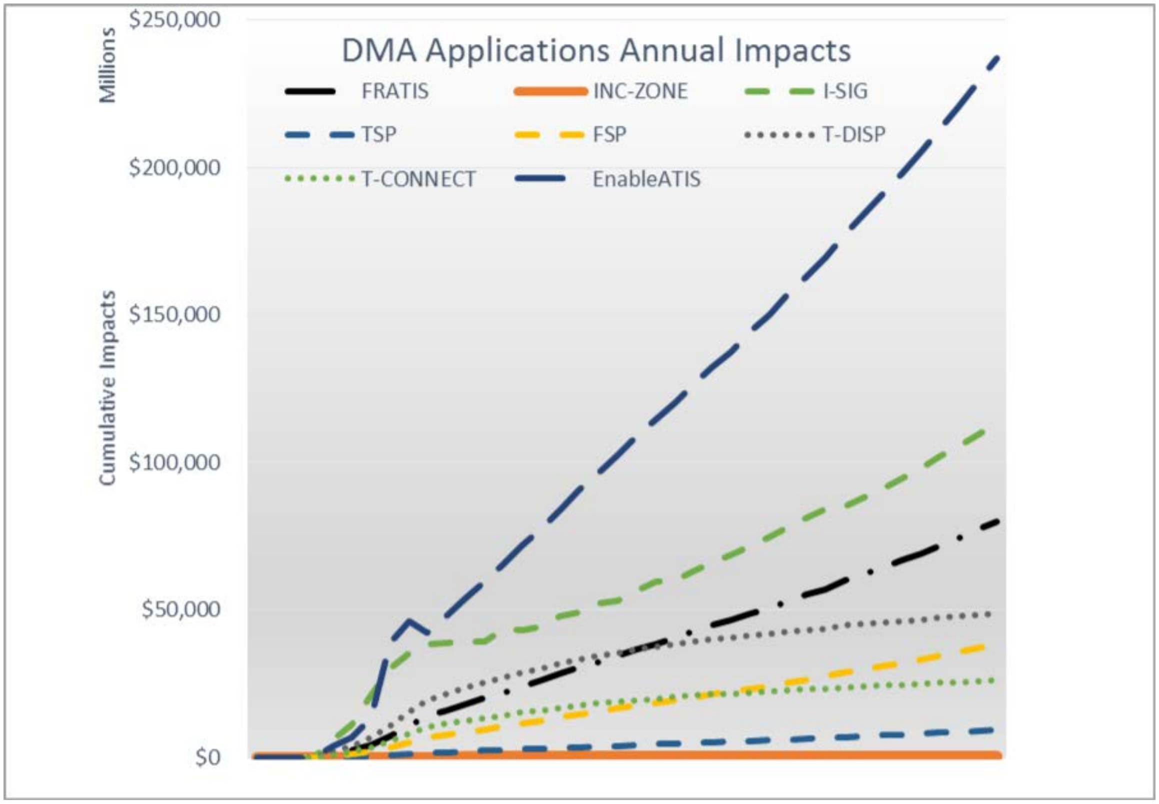
The national impacts estimation showed significant mobility benefits for the assessed applications. However, some of the applications have important benefits under impact areas outside mobility, despite the negligible to slightly negative impacts that they may have on mobility. Therefore, an accurate and comprehensive assessment of those applications' impacts should take into account non-mobility benefits (e.g., safety and environmental benefits) as well. This section covers the applications for which either an IA was conducted or were studied using the AMS Testbeds study (a study of DMA applications using multiple simulation testbeds from across the country).

- INFLO: SPD-HARM and Q-WARN allow drivers on the freeway to take action before approaching congestion. These applications reduce the need to slow down or stop suddenly and primarily offer safety benefits. In fact, the combined SPD-HARM/Q-WARN prototype led to significantly reduced magnitudes of speed drops (shockwaves) between vehicles. However, those important safety benefits come with a mobility trade-off. These applications increase the geographic impact of existing bottlenecks on freeway speeds by expanding the upstream distance that is affected by congestion. This is reflected by the mobility disbenefits observed for SPD-HARM and Q-WARN in the national mobility impacts estimation of this report.

- MMITSS: I-SIG, FSP, and TSP bring significant reductions in travel time on arterials. The volume driver for the associated national impacts extrapolation is the arterial VMT. For I-SIG, the annual impacts are higher, with between 25% and 50% penetration rates, which are achieved between the years 2025 and 2035. The growth of arterial VMT over the years also contributes to this increase in annual impacts. The mobility impacts of TSP and FSP follow a similar trend. However, these impacts are smaller than I-SIG since TSP and FSP are designed to specifically benefit transit and freight vehicles. Additional benefits may be derived from vehicles experiencing lower travel time delays when the priority phases are activated. There may also be disbenefits from vehicles incurring delays on side streets where the priority phases are not implemented. The IA study reported that the system wide delay was higher than the baseline when FSP was implemented.
- R.E.S.C.U.M.E.: INC-ZONE leads to a reduction in travel time for vehicles passing through incident zones. The volume driver for the national impacts extrapolation is the number of incidents on the national level. The annual resulting mobility impacts follow a trend similar to the application deployment curve. This indicates that the benefits of the application increase with higher penetration rates. The cumulative benefits increase linearly over the years.
- EnableATIS: This is a bundle of four applications, but it was deployed in the AMS Testbeds study as a single application that could provide pre-trip and en-route information to users. The benefits exhibited were from users receiving information about non-recurrent bottlenecks and either adjusting their departure times or re-routing to a faster route.
- IDTO: The IDTO bundle consists of the T-DISP and T-CONNECT applications. The T-DISP application matches network users with available transit services and T-CONNECT is a connection protection application. The impacts of these applications were considerably high. This application holds a lot of potential because of the high transit ridership numbers and the possibility of attracting more riders through additional benefits like travel time reliability.
- FRATIS: The FRATIS application was deployed in the AMS Testbeds study as a single application that could provide pre-trip information, routing guidance, and drayage optimization. The study was carried out using the Phoenix AMS testbed. The FRATIS application showed high travel time benefits. The AMS study was carried out on an urban network, which did not study the impacts of FRATIS on freeways. If deployed on freeways, the application could have considerably higher impacts.

Figure 2 shows the impact comparison for all applications. This figure is meant to compare the extent of benefits that may potentially be observed for the applications when they are deployed. The benefits plotted in the figure are cumulative. The total number of users/vehicles that benefit from the application affects the cumulative impact. For example, INC-ZONE is an application that benefits users who are passing through an incident zone. Therefore, the benefits of INC-ZONE are very low compared to EnableATIS, which can potentially benefit anyone. The figure only shows the mobility benefits (i.e., travel time benefits) resulting from the deployment of these applications. The INFLO application impacts were not included in Figure 2 since the primary impacts for this bundle are safety-related, and this figure only estimates mobility impacts (which are negative for INFLO).

Figure 2. Comparison of the Mobility Impacts of All Applications (Except INFLO) Evaluated in This Report



Source: Booz Allen Hamilton, June 2016

From a cost perspective, this study looks at the comprehensive set of costs incurred for the national deployment of each application (“from the ground up”). This is a conservative assumption, and in reality, the DMA applications will leverage the existing CV environment and infrastructure, which leads to a more realistic and accurate cost estimation. As those applications move from limited prototype tests to actual deployments, an accurate collection of cost data and performance measures will allow a more realistic benefits and costs computation that captures the real effect of DMA applications as they are deployed along with other CV applications in a certain area. Such a real-world assessment will further pinpoint synergies between applications, their combined impacts, and their actual deployment costs.

Chapter 1. Introduction

1.1 Program Overview

The ITS JPO created the DMA program to develop applications that fully leverage frequently collected and rapidly disseminated multi-source data. This data is gathered from connected travelers, vehicles, and infrastructure to increase efficiency and improve individual mobility while reducing negative environmental impacts and safety risks. The goals of the program are to:

- Develop mobility applications that use frequently collected and rapidly disseminated data drawn from CVs, travelers, and infrastructure
- Assess mobility applications that improve the capability of the transportation system to provide safe, reliable, and efficient movement of goods and people
- Identify mobility applications (for possible future investment) that have the potential to improve the performance of dynamic decision making by both system managers and users
- Accelerate the development, commercialization, and deployment of mobility applications through collaboration with the public, private, and academic communities
- Position the federal government as a technology steward in transforming transportation through connectivity linking travelers, vehicles, and infrastructure.

To address these objectives, the DMA program is composed of three phases taking place over eight years: Foundational Analysis (Phase 1); Research, Development, and Testing phase (Phase 2); and Pilot Deployments & Demonstrations (Phase 3). There are two key challenges in developing and deploying mobility applications:

- **Technical Soundness** – Are the DMA bundles technically sound and deployment-ready?
- **Transformative Impact** – Are DMA bundle-related benefits big enough to warrant deployment?

To overcome these two challenges, a series of systems engineering documents, such as concept of operations (ConOps) and system requirements (SyRs), were created during the development phase of each application. Also, an open source portal was setup to share code from open source bundle prototype development. Finally, demonstrations and field tests of the application prototypes were conducted both in isolation and in combination. Moreover, the DMA program developed projects to engage stakeholders to set transformative impact measures and goals, assess whether the prototype efforts show impacts when demonstrated, estimate impacts associated with broader deployment, and utilize analytic testbeds to identify synergistic bundle combinations.

The seventeen DMA applications are divided into six bundles. The classification into bundles is based on the functionalities of the applications under them. For example, INFLO is a set of freeway applications designed to make the operations smoother. As a result of DMA research and development activity, 16 of the 17 applications have at least one prototype, demonstrated in at least one location[1]. Independent impact assessment (IA) efforts were conducted for each of the bundles, with results based on either data collection/analysis from the prototype demonstrations, or on the simulation of single-application scenarios.

1.2 Project Overview

As part of the DMA program evaluation effort, a national-level impacts and cost estimation was conducted in order to provide a rough order of magnitude of the costs associated with a national deployment of the DMA applications, and the monetized mobility impacts that would result from such a national deployment. Even though this quantitative analysis is centered on the mobility impacts exclusively, several of the DMA applications may more significant affect other impact areas (e.g., safety or the environment). Therefore, a holistic benefits capture needs to be taken into account in order to fully complete assess the value of the DMA applications.

With the development of a nationwide benefits and costs model, the team intends to identify the applications that can be deployed in the near term as well as the potential benefits and costs that can be anticipated over the future years.

The analysis duration is 2021 to 2060. This period extends through the anticipated deployment of CVs in 2021 and continues past the year 2058, when NHTSA indicates the OBU deployment rate will reach 100%. Therefore, a 0% deployment is assumed between years 2015 and 2021, and a 100% deployment is achieved in year 2058 and beyond. Impacts and costs are quantified and monetized with some assumptions.

For the evaluation, the inputs are results from the IA and prototype development (PD) projects carried out as part of the DMA program. The IA and PD projects developed field tests or computer evaluation studies in the form of simulation testbeds. The results from these IA studies formed the basis for the analysis. Furthermore, some results from single-application scenarios of the AMS simulation testbeds project are also used to fill gaps in the absence of quantitative IA results for some of the bundles.

The sources that were used for all of the results are documented for each application in this report.

The primary mobility measure used across the analysis is travel time savings. Other safety and environmental impacts resulting from the deployment of DMA applications are not assessed as part of this analysis, since they are not easily quantifiable for a nationwide analysis. For example, the safety benefits of the INFLO applications are not considered in this evaluation, although they have the potential to reduce rear-end crashes and therefore result in mobility benefits.

Specifically, six bundles of applications are evaluated under this task. Some of the applications are prototyped together and are evaluated as is. Only those applications for which the IA and PD results

---

[1] The exception is the Cooperative Adaptive Cruise Control (CACC) application, where feasibility testing is now transitioning to prototyping and field testing.

are available are evaluated. The costs assessments were also carried out for the same set of applications.

The IA or AMS testbed results were available and provided for all the applications evaluated in this report.[2] They are listed below:

INFLO - Intelligent Network Flow Optimization

- Q-WARN+SPD-HARM - Queue Warning and Dynamic Speed Harmonization. The Q-WARN and SPD-HARM applications are evaluated together

MMITSS - Multi-modal Intelligent Traffic Signal Systems

- I-SIG - Intelligent Traffic Signal System
- TSP - Transit Signal Priority
- FSP - Freight Signal Priority

R.E.S.C.U.M.E. - Response, Emergency Staging and Communications, Uniform Management, and Evacuation

- INC-ZONE - Incident Scene Work Zone Alerts for Drivers and Workers

EnableATIS

- ATIS - Multimodal Real Time Traveler Information

FRATIS – Freight Advanced Traveler Information System

- DR-OPT + F-ATIS and F-DRG – Drayage optimization, Route Guidance and Freight-Advanced Traveler Information

IDTO - Integrated Dynamic Transit Operations

- T-CONNECT
- T-DISP

The cost estimation process is conducted by first identifying and mapping individual cost elements required to enable the functionality of each application. Each of the cost elements considered in this analysis are categorized as infrastructure, in-vehicle, software, or training costs. Unit costs, O&M costs, and expected useful life data for each element is collected from the AASHTO LCC model. Using the national level volume drivers and unit costs for each cost element, the unit costs are extrapolated to the entire United States and projected based on the NHTSA deployment rates (2021 through 2060). The application-specific final annual and cumulative cost estimation results are broken down into different cost categories and are provided in the Cost Estimation Results section of this report.

---

[2] Note that no quantitative IA results were provided for FRATIS and EnableATIS. Therefore, single-application results from the AMS testbeds analysis are used for the impacts estimation for those two bundles.

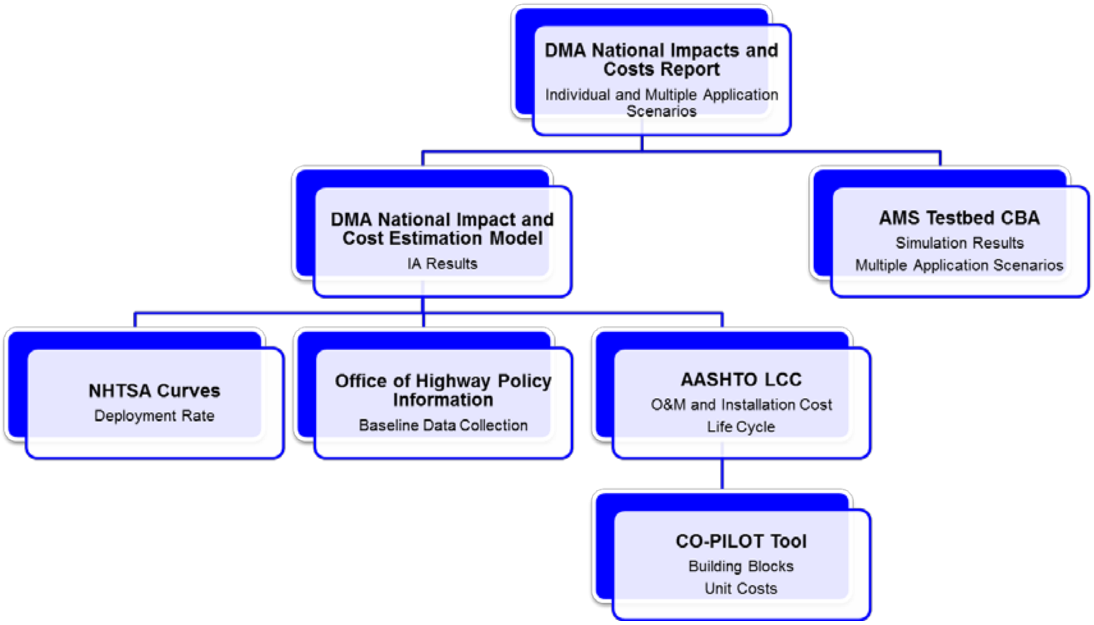
1.3 Scope of the Analysis

The scope of this evaluation task is limited by the data available to carry out a multi-decade nationwide analysis of benefits and costs. Some statements defining the scope of this project include:

1. The analysis period is 2021 to 2060. The CV deployment during this period is according to the deployment curves provided by the National Highway Traffic Safety Administration (NHTSA).
2. The compliance rate and adoption rate are assumed to be accounted for in the deployment rate percentages. For example, when 25% deployment is achieved, it means that the 25% is a representative number depicting the number of users that are equipped and make use of the technology.
3. The impacts and costs are assessed using results from the IA projects under the DMA program. Some results from the AMS testbeds project are also used where necessary. The impacts and costs are assessed only for the applications that were measured by the IA contractors. These do not cover all of the defined DMA applications.

The project scope has a few dependencies. These are outlined in Figure 3 below. The evaluation model built under this task has three basic components: the baseline development, the national level impacts estimation, and the application-specific cost estimation. Figure 3 below shows the key components used in this analysis. The CO-PILOT tool is used in the development of the AASHTO Life Cycle Costs (LLC) model. The AASHTO LLC model is the basis for the national level DMA cost estimation cost model. The Highway Policy Information database is used for the baseline development and extrapolation volume drivers. Vehicle miles traveled (VMT), number of vehicles on the road, and miles traveled by functional system are a few examples of the datasets from this database used in the model. The OBU and safety application deployment curves provided by NHTSA are used to estimate the deployment rates of applications across the analysis duration (i.e., 2021-2060).

Figure 3. DMA National Impacts and Cost Estimation Key Components



Source: Booz Allen Hamilton, June 2016

The basis for estimating impacts are obtained from the IA projects. These impacts, along with baseline data, can be extrapolated nationally for the entire analysis duration.

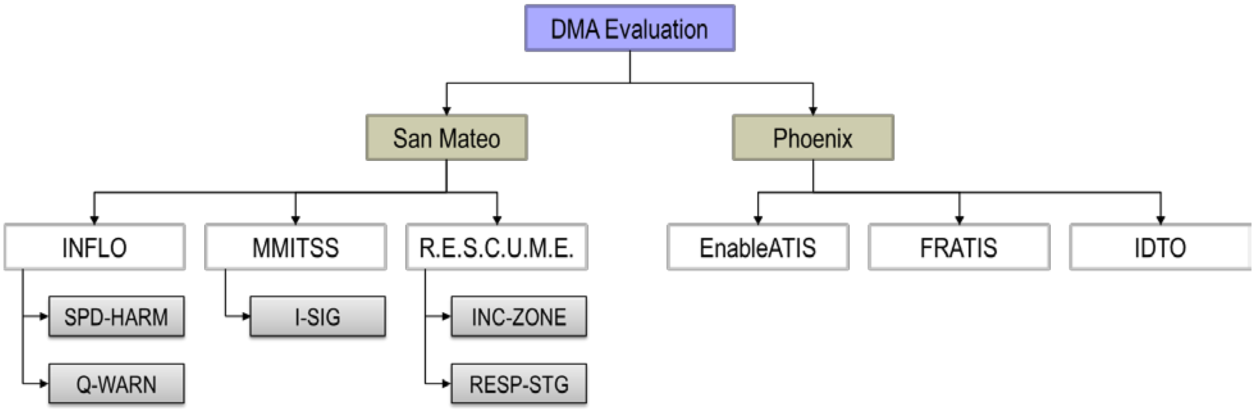
The AMS testbeds project also contributes to the DMA program evaluation. This project uses simulation testbeds from across the country to evaluate the different DMA applications. The AMS testbed results for single-application scenarios are used for the national impacts estimation where IA results are not available. Figure 4 provides an overview of the AMS testbed project and the applications it studies. Most of the evaluations are conducted for the San Mateo testbed and the Phoenix testbed.[3] The AMS testbed project also leverages the DMA impact-cost model to estimate regional impacts and costs of deploying multiple applications in a region. Although the DMA model was built for nationwide analysis, it is robust enough for regional analysis with some modifications.

The application-specific final results of the DMA national impact and cost estimation model are included in this report. While the scope of this analysis does not cover multiple application scenarios, those are captured in the AMS testbed analysis.

---

[3] “AMS Testbed Evaluation Report for DMA Program,” Draft version 1.0, *U.S. Department of Transportation*, December 2015.

Figure 4. DMA Evaluation Testbeds and their Corresponding Applications



Source: Booz Allen Hamilton, December 2015

As in the AMS testbeds project, the DMA evaluation model treats each bundle as a specific set of applications that are deployed on a particular facility. For example, the INFLO applications are designed for freeways and will be deployed only on freeways and MMITSS applications will be deployed on arterials.

1.4 Application Descriptions

Based on the IA results received by the project team, the national impacts and costs estimation analysis for the following applications is included in this report:

- INFLO Bundle: Q-WARN and SPD-HARM
- MMITSS Bundle: I-SIG, TSP, and FSP
- R.E.S.C.U.M.E. Bundle: INC-ZONE
- EnableATIS Bundle: ATIS
- FRATIS Bundle: DR-OPT and Freight Specific Dynamic Travel Planning and Performance (FSDTPP)
- IDTO Bundle: T-CONNECT and T-DISP

A complete description of all the bundles under the DMA program and the applications within each bundle are listed below.

1.4.1 INFLO

The INFLO bundle consists of three different applications:

1. **Q-WARN** provides a vehicle operator with sufficient warning of an impending queue backup, thereby minimizing the occurrence and impact of traffic queues by using CV technologies, including vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications.

2. **SPD-HARM** dynamically adjusts and coordinates vehicle speeds in order to maximize traffic throughput and reduce crashes. By reducing speed variability among vehicles, traffic throughput is improved, flow breakdown formation is delayed or even eliminated, and collisions and severity of collisions are reduced.
3. **CACC,** or Cooperative Adaptive Cruise Control, dynamically and automatically coordinates cruise control speeds among platooning vehicles, thereby coordinating in-platoon vehicle movements and reducing drag.

1.4.2 MMITSS

The Multi-Modal Intelligent Traffic Signal Systems bundle (MMITSS) is a next-generation traffic signal system that seeks to provide a comprehensive traffic information framework to service all modes of transportation. The five applications are described below.

1. **I-SIG** aims at maximizing the throughput of passenger vehicles and minimizing the delay of priority vehicles under saturated conditions. I-SIG also minimizes the total weighted delay during under-saturated conditions.
2. **TSP** allows transit agencies to better manage bus service by granting buses priority at traffic signals.
3. **PED-SIG** integrates information from roadside or intersection sensors with new forms of data from pedestrian-carried mobile devices.
4. **PREEMPT** will integrate with V2V and V2I communication systems in preempting signal phases for emergency vehicles.
5. **FSP** provides signal priority near freight facilities based on current and projected freight movements.

1.4.3 R.E.S.C.U.M.E.

The Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) bundle consists of three different applications:

1. **EVAC** application supports region-wide evacuations. It provides dynamic route guidance and other relevant information to those using their own transportation. It notifies transit users of times and locations. It also provides responders with information to identify and locate people who require guidance and assistance.
2. **RESP-STG** is a responder staging application that aims at enhancing the situational awareness of and coordination among emergency responders by providing valuable inputs to responder and dispatcher decisions and actions, like route guidance, road conditions, and where previously-arrived response vehicles are parked.
3. **INC-ZONE** is an incident zone application that warns drivers who are approaching temporary work zones at an unsafe speed and/or lane. It also warns public safety personnel and other officials working in the zone.

1.4.4 EnableATIS

Enable Advanced Traveler Information Systems (EnableATIS) consists of four applications:

1. **ATIS**, or Multimodal Real Time Traveler Information, integrates travel-time reliability in a multimodal environment by integrating data from different sources and disseminating it to users via different media.

2. **S-PARK**, or Smart Park and Ride, monitors and reports the occupancy of parking spaces in real time, calculates the average travel distance and time to the parking facility and suggests alternative location.
3. **T-MAP,** Universal Map Application, enables transportation agencies to place real-time information on a universal map by addressing the issue of proprietary map applications.
4. **WX-INFO**, or Real Time Route Specific Weather Information, provides real-time, highly-localized weather information to improve the mobility and safety of users of both motorized and non-motorized modes of transportation.

1.4.5 FRATIS

The Freight Advanced Traveler Information System (FRATIS) consists of three different applications that are freight-related:

1. **DR-OPT** combines container load matching and freight information exchange systems to fully optimize drayage operations using powerful algorithms to leverage data from multiple sources.
2. **F-ATIS** and **F-DRG** are modeled as a single application called Freight Specific Dynamic Travel Planning and Performance. It includes all of the traveler information, dynamic routing, and performance monitoring elements that freight-truck users need in one application and leverages existing data in the public domain, as well as emerging private sector applications.

1.4.6 IDTO

Integrated Dynamic Transit Operations (IDTO) consists of three applications:

1. **T-CONNECT** aims to improve rider satisfaction and reduce expected trip time for multimodal travelers by protecting transfers between both transit and non-transit modes and facilitating coordination between multiple agencies.
2. **T-DISP** aims at advancing demand-responsive transportation services through the use of existing technology systems and the expansion of transportation options. It seeks to match travelers’ requests for trips with available transportation providers’ services.
3. **D-RIDE** is a car-pooling system that provides drivers and riders with the flexibility of making real-time transportation decisions. It aims to increase the use of non-transit ride-sharing options, including carpooling and vanpooling, and improving the accuracy of vehicle capacity detection.

1.5 Organization of the Report

The remainder of this report is organized according to the following sections:

- **Baseline Development:** This section includes a detailed description of the baseline assumptions, baseline forecasts (for vehicle miles traveled, hourly wages, and incidents on freeways), as well as a detailed list and justification for the volume drivers used for each application.
- **Impact Estimation:** This section provides a detailed description of the overall approach and impact estimation specific assumptions, which were made in this analysis. An explanation of the IA results, unit impact estimation, NHTSA deployment rates, extrapolation methodology, and monetization of the impacts are all included in this

section. The final annual and cumulative application-specific impact estimation results for INFLO, MMITSS, R.E.S.C.U.M.E., EnableATIS, IDTO, and FRATIS bundles are also presented in this section.

- **Cost Estimation:** The cost estimation section provides a detailed description of the overall cost estimation methodology and the data sources used to identify and evaluate cost breakdown structures for each application. Unit cost estimation and national level extrapolation of the aggregated costs based on the NHTSA deployment rates are included. At the end of this section, annual and cumulative application-specific cost estimation results for INFLO, MMITSS, R.E.S.C.U.M.E., EnableATIS, IDTO, and FRATIS are presented.
- **Limitation of the Analysis:** This section includes the major limitations associated with the impacts and costs estimation, including the limitation of IA results and NHTSA deployment rates.
- **Conclusion:** The final section provides a brief interpretation of the results.

Chapter 2. Baseline Development

The baseline includes three essential components: scope of the analysis; baseline forecast (i.e., growth of VMT, incidents); and technology market penetration rates. The volume drivers estimated in the baseline development stage are used to extrapolate results for each application. Table 2 provides a summary of the components developed in the baseline with sources of information.

Table 2. Summary of Baseline Components

Baseline Component	Data	Source
Scope of the Analysis	Geographic Scope	Entire United States
Scope of the Analysis	Time Period of Analysis	2021-2060
Scope of the Analysis	Discount Rate	All results are expressed in 2012 dollars
Scope of the Analysis	Stakeholders Impacted	DOT, states, localities, individual drivers, U.S. taxpayers, general public
Baseline Forecasts	Vehicle Miles Traveled (VMT) by Functional System (Freeways, Arterials, and Locals)	Highway Policy Information (national)
Baseline Forecasts	Hourly Wages for estimating Value of Time (VoT)	Highway Policy Information (national)
Baseline Forecasts	Incidents	Highway Policy Information (national)
Technology Market Penetration/ Adoption Rates	On-Board Equipment	NHTSA OBU deployment curves (national)
Technology Market Penetration/ Adoption Rates	Roadside Units Equipment	NHTSA OBU deployment curves (national)

Baseline Component	Data	Source
Technology Market Penetration/ Adoption Rates	Application Deployment	NHTSA safety applications deployment curves (least aggressive curve) (national)

Source: Booz Allen Hamilton, June 2016

2.1 Baseline Assumptions

The baseline assumptions used for the project are the following:

- The analysis duration is from 2021 through 2060.
- The assessment is made for the United States only.
- Future modes of transport, like car-sharing and car-pooling, are not considered.
- Future changes in the composition of vehicle mix are not considered for analysis. Any resulting changes in the VMT trends are also not considered. The advent of electric cars and driverless cars may increase the VMT on the roads, but these impacts are not considered.
- The VMT sensitivity to fluctuations in fuel prices are not considered in the report.
- The impacts of future recession scenarios are not considered in the model.
- The baseline for the cost estimation effort is assumed to be zero (i.e., no application deployment). The scope of the cost estimation analysis is to capture the additional cost attributed to the deployment of each application, assuming no infrastructure is available at the beginning of the period of analysis.

2.2 Baseline Forecasts

Each of the identified baseline elements were extrapolated across the entire analysis duration. This section provides further details about the projection of the growth trends for these components.

2.2.1 Vehicle Miles Traveled (VMT) by Functional System (Freeways, Arterials, and Locals)

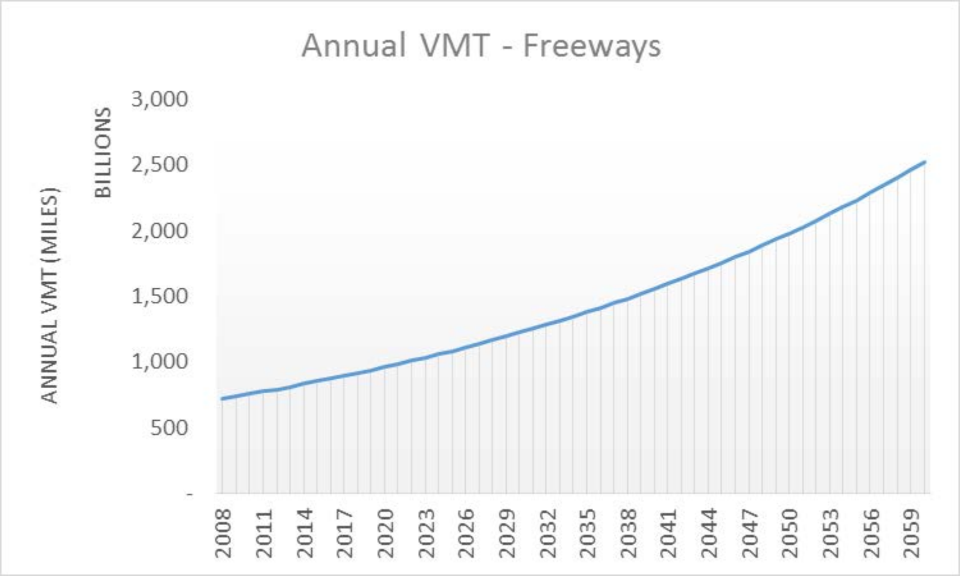
VMT traveled is used as a volume driver for most applications. As part of the baseline development, data was collected for annual VMT traveled in the United States (excluding Puerto Rico). The source of the data was the Highway Policy Information database. Data was available by functional system (arterial, freeway, and local) for the year 2008. The projections for the years after were made using the annual growth rate. The annual growth rate was estimated from several years (specifically, 1980 to 2008) of annual VMT data, which was not classified by functional system. Because of this, a uniform growth rate is applied for freeways, arterials, and locals.

The estimated VMT annual growth rate is 2.4%.

2.2.1.1 *Freeways VMT Forecast*

The freeway annual VMT quantities are large and are expected to grow rapidly over the next few decades (see Figure 5). In year 2060, the estimated annual VMT is over 2,500 billion miles. The estimated lane miles annual growth rate is approximately 0.26% (estimated using lane miles data from Highway Policy Information database for years). This growth in lane miles may saturate at some point and curb the growth of the VMT, but that is not accounted for in this study.

Figure 5. Freeway VMT Projections

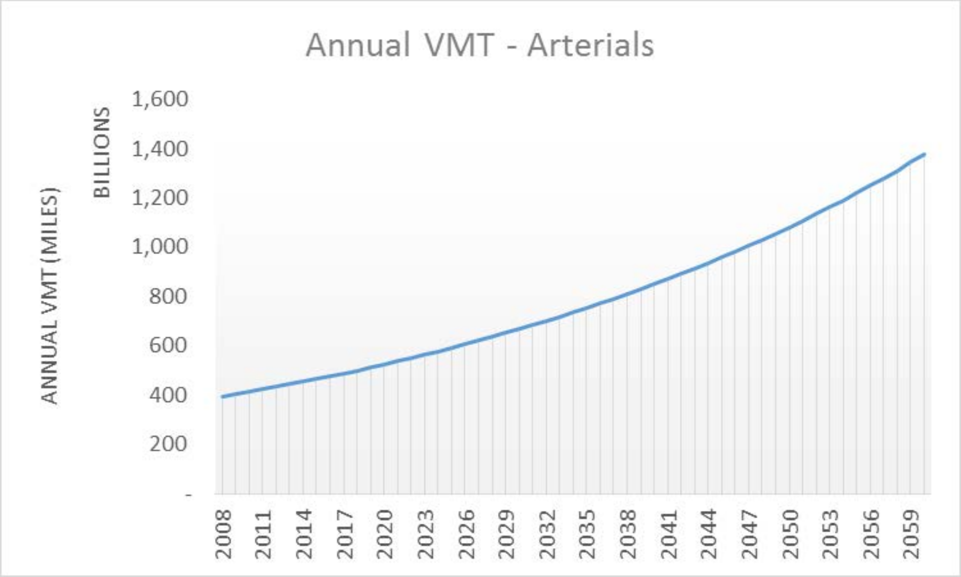


Source: Booz Allen Hamilton, December 2015

2.2.1.2 *Arterials VMT Forecast*

The arterial VMT growth may saturate more quickly than the freeway VMT growth. The arterials connect more populated areas and there is limited space available to expand most of them. Given the available data, it is assumed that the annual arterial VMT will grow to 1,400 billion miles in 2060 (see Figure 6).

Figure 6. Arterial VMT Projections

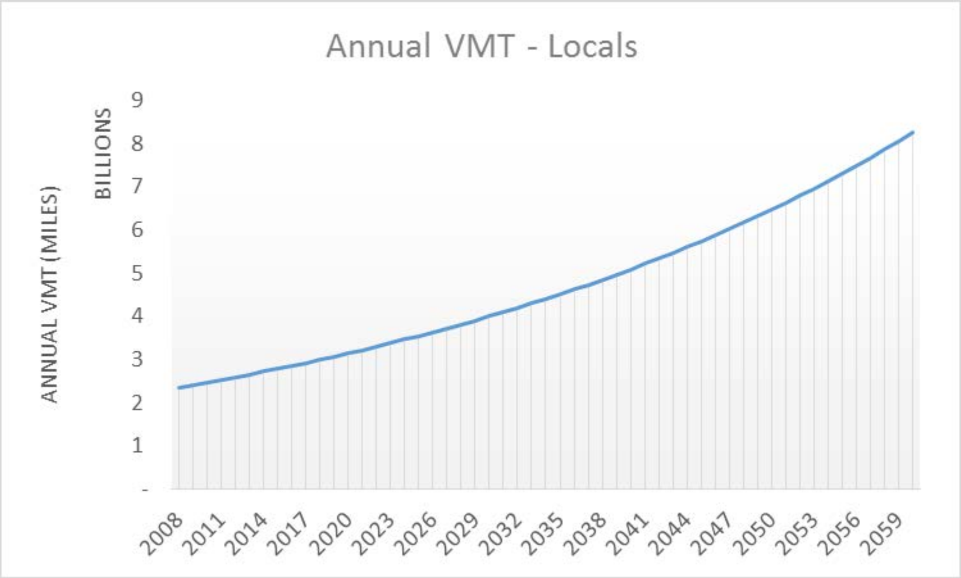


Source: Booz Allen Hamilton, December 2015

2.2.1.3 Local Roads VMT Forecast

The local roads VMT travel is very small compared to both arterial and freeway VMTs (see Figure 7). Very few applications may be deployed on local roads. The installation costs and maintenance costs may not be justified for the deployment of applications on local roads.

Figure 7. Local Roads VMT Projections

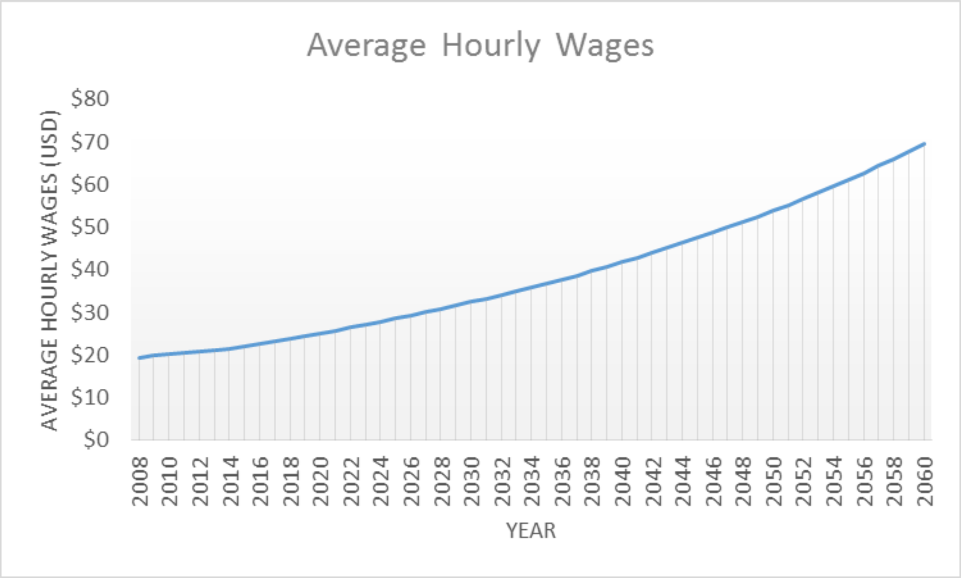


Source: Booz Allen Hamilton, December 2015

2.2.2 Hourly Wages

Growth in hourly wages are used to estimate the VoT, which is used to monetize the impacts of the DMA applications. The annual growth rate for the hourly wages forecast is 2.57% (calculated using hourly wage data from Bureau of Labor Statistics).

Figure 8. Average Hourly Wages Forecast



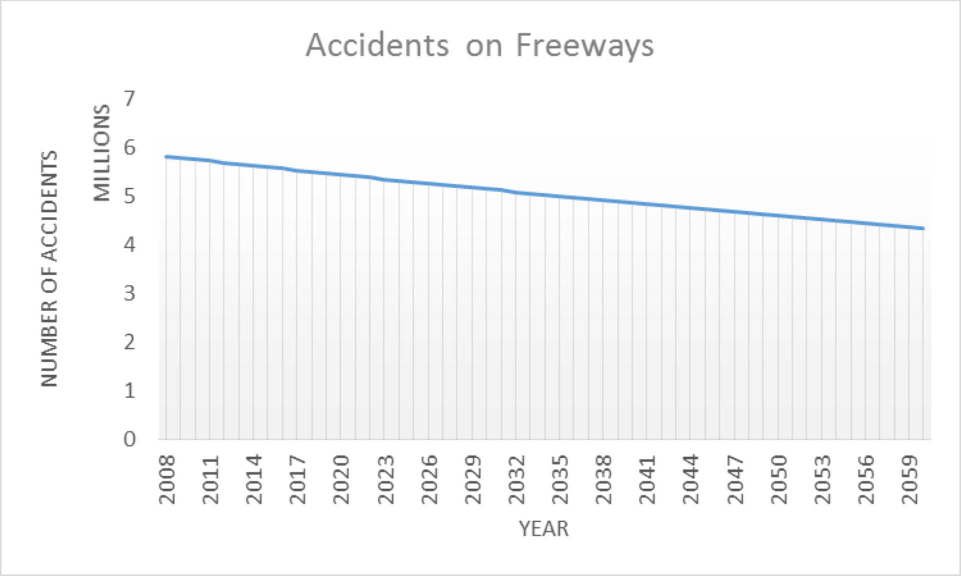
Source: Booz Allen Hamilton, June 2016

2.2.3 Incidents on Freeways

The highway incidents data was collected from Bureau of Transportation Statistics (BTS) database. From the incidents data over the past few years, it can be observed that the number of incidents is declining. The annual decline rate is -2.05%.

The number of incidents on highways is partly a function of the number of vehicles on the roads. Due to this, the crashes/vehicles ratio was estimated for the years when the incidents data and number of vehicles data (HPI database) were available. The annual average changes in this ratio was then used to project the crashes/vehicles ratio for the future years (i.e., 2015-2060). The projected number of vehicles for each of these years (estimated with an annual vehicle growth rate of 1.52% based on HPI data) was then used to obtain the crashes for each year of analysis (see Figure 9).

Figure 9. Number of Incidents on Freeways Projection

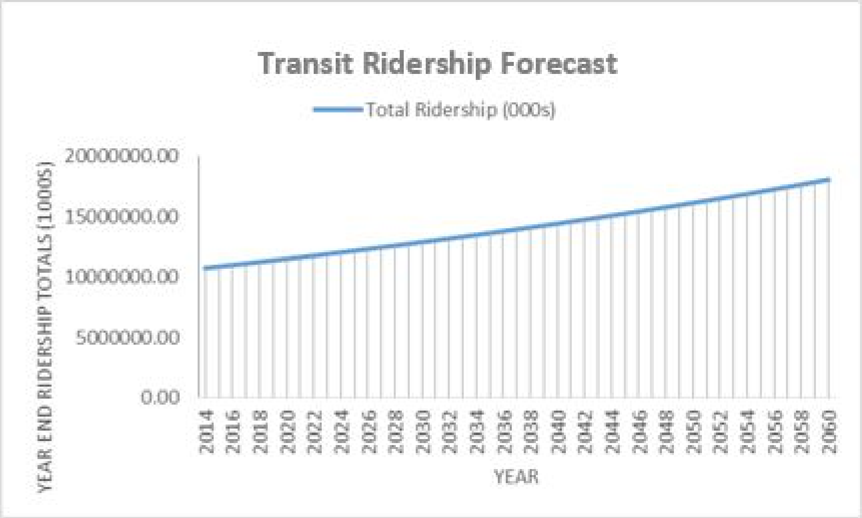


Source: Booz Allen Hamilton, June 2016

2.2.4 Transit Trips

APTA data were used to project the yearly transit trip totals. This data was available for the years 1990 to 2014. The compound annual growth rate (CAGR) for the total ridership on all transit modes was 1.133% (see Figure 10).

Figure 10. Transit Ridership Projection



Source: Booz Allen Hamilton, June 2016

2.3 Volume Drivers for Each Application

The volume drivers used for each of the applications in this study along with the justifications for choosing those particular volume drivers are listed in Table 3.

Most applications can use VMT as the volume driver. The VMT, however, is separated out by its functional system (e.g., freeway, arterial, or local). The VMT forecasts for the applicable functional system are used to estimate the impacts for these applications. For example, Q-WARN and SPD-HARM are both applications that may be deployed on freeways in the future. In order to estimate impacts for these for future years, the freeway VMT projections are used. For I-SIG, which is a signal-based application, arterial VMT forecasts are used as volume drivers, since I-SIG will likely be deployed only on arterials.

In addition to using the volume drivers to estimate impacts, the following adjustments are used to estimate transit-only miles and freight-only miles and then to convert the VMT to person miles traveled using the occupancy rates:

- Using the highway policy information data table on annual VMT from 2010, it is estimated that the percentage of transit vehicle miles traveled on arterials is 0.464 percent and the freight vehicle miles traveled on arterials is 7.995 percent.[4]
- Average vehicle occupancy is 1.69 for vehicles other than freight and transit vehicles.[5]Freight vehicle occupancy is assumed to be 1.0.

Average transit vehicle occupancy is 9.2.[6]

Table 3. Volume Drivers for the DMA Applications

Bundle	Application(s)	Volume Drivers	Justification
INFLO	Q-WARN and SPD-HARM – evaluated together	VMT Freeways	INFLO application harmonizes speeds of vehicles on a roadway and hence is better deployed on freeways. Arterial traffic could get intermittent stops depending on the intersection control in place.
MMITSS	I-SIG	VMT Arterials and Locals	MMITSS application aims at optimizing the signal control which is not present in a freeway setting.
MMITSS	TSP and FSP	VMT Arterials and Locals	For the TSP and FSP applications, transit and freight VMT on Arterials and Locals were used as volume drivers.

---

[4] "Annual Vehicle Distance Traveled in Miles and Related Data – 2012 (1) By Highway Category and Vehicle Type," *U.S. Department of Transportation*, January 2014, https://www.fhwa.dot.gov/policyinformation/statistics/2012/pdf/vm1.pdf.

[5] "Summary of Travel Trends: 2009 National Household Travel Survey," *U.S. Department of Transportation*, June 2011, http://nhts.ornl.gov/2009/pub/stt.pdf.

[6] "Transportation Energy Data Book, Edition 34,"*U.S. Department of Energy*, September 2015, http://cta.ornl.gov/data/index.shtml.

Bundle	Application(s)	Volume Drivers	Justification
R.E.S.C.U.M.E.	INC-ZONE	Incidents on Freeways	INC-ZONE application aims at delivering alerts about incidents ahead using CV technology with one of the most important aspect being threat determination. The application uses the vehicle location to identify whether the incident location is along the vehicle's path in terms of lane and heading. This is easier in a freeway setting due to the wider geographic range of the road.
EnableATIS	ATIS, S-PARK, T-MAP, WX-INFO	VMT Arterials and Locals	EnableATIS uses information on travel-time, travel-speeds, incidents, etc., to provide pre-trip and en-route advisories to equipped vehicles and is therefore used in both arterials and freeways.
IDTO	T-CONNECT	Transit Ridership	T-CONNECT is deployed in transit vehicles which will travel mostly on arterials and local roads.
IDTO	T-DISP	Transit Ridership	T-DISP is deployed in transit vehicles which will travel mostly on arterials and local roads.

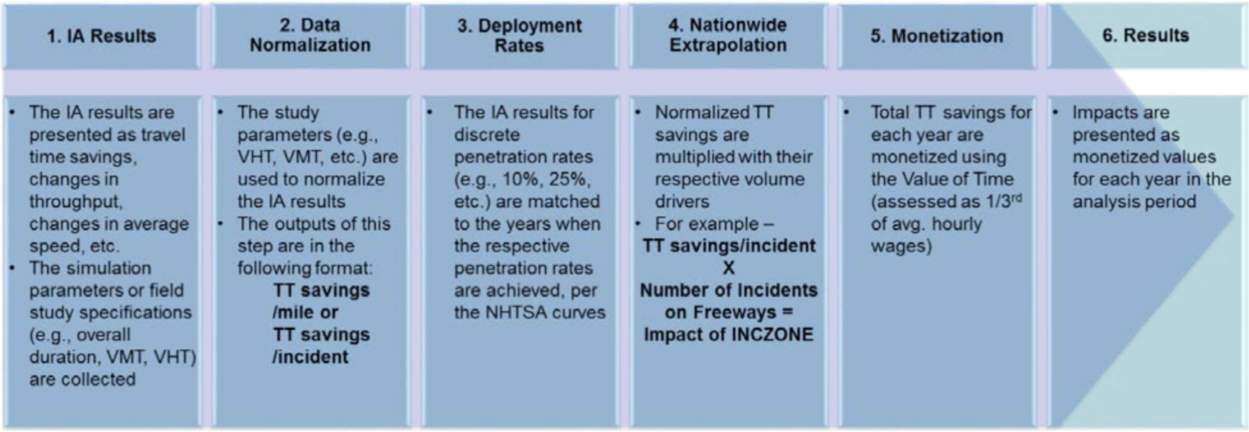
Bundle	Application(s)	Volume Drivers	Justification
FRATIS	F-ATIS, DR-OPT, F-DRG	Truck VMT Arterials	FRATIS applications provide traveler information system, route guidance, and drayage optimization and is therefore used in both arterials and freeways. However, the AMS testbeds study deployed these as a single application, which is how it was treated for Impacts Estimation as well.

Source: Booz Allen Hamilton, June 2016

Chapter 3. Impacts Estimation

3.1 Overview of the Approach

Figure 11. Impacts Estimation Overview



1. IA Results	2. Data Normalization	3. Deployment Rates	4. Nationwide Extrapolation	5. Monetization	6. Results
• The IA results are presented as travel time savings, changes in throughput, changes in average speed, etc. • The simulation parameters or field study specifications (e.g., overall duration, VMT, VHT) are collected	• The study parameters (e.g., VHT, VMT, etc.) are used to normalize the IA results • The outputs of this step are in the following format: **TT savings /mile or TT savings /incident**	• The IA results for discrete penetration rates (e.g., 10%, 25%, etc.) are matched to the years when the respective penetration rates are achieved, per the NHTSA curves	• Normalized TT savings are multiplied with their respective volume drivers • For example – **TT savings/incident X Number of Incidents on Freeways = Impact of INCZONE**	• Total TT savings for each year are monetized using the Value of Time (assessed as 1/3rd of avg. hourly wages)	• Impacts are presented as monetized values for each year in the analysis period

Source: Booz Allen Hamilton, December 2015

Figure 11 shows the impacts estimation process used in this study. In summary, the IA results are converted into unit impacts, as described in the previous section. Then, the unit impacts (for discrete penetration levels like 10%, 25%, or 50%) are appropriately applied to the deployment year when the respective CV penetration is achieved. Further, the unit benefits now associated and interpolated to match the corresponding level of penetration for each of the years in the analysis period are extrapolated using the applicable volume driver quantities and then monetized using VoT values. The results are presented as charts and tables of annual and cumulative impacts.

3.1.1 Impacts Estimation Assumptions

The basic assumptions that guide the impacts estimation are as follows:

- The impacts analysis is carried out for mobility impacts only. Safety and environmental impacts of the DMA applications are not estimated in this study. They are reported as is from the IA studies, but not used in the impacts estimation model.
- Mobility impacts are assessed using a single measure in this study: travel time (TT) savings. TT savings is a robust measure that can be used to assess a significant portion of the benefits of most DMA applications considered in this study. TT savings are typically estimated in hours or minutes. This makes it easy to monetize this measure using VoT as a multiplier.

TT savings are reported for all of the DMA applications, which makes it a well-suited measure for comparing the impacts of different applications across the board. The other mobility measures, like average speeds and travel time reliability, cannot be monetized in a simple manner. Travel time reliability is also an important performance metric; however, data on changes to travel time reliability was not available for this study.

- Indirect mobility benefits are not assessed. Safety and environmental impacts are not assessed. For example, R.E.S.C.U.M.E. applications improve safety, which in turn has a positive mobility benefit. But this tertiary mobility impact is not assessed in this study.
- All reported environmental and safety benefits are documented in the report based on the IA studies (where the IA studies did not quantify results, AMS Testbed study results were used).

3.2 IA Results

The inputs to the impacts estimation model are results of the IA and PD projects. Each IA study generated a report capturing the impacts of the corresponding DMA application bundle. The IA consists of a simulation testbed or a field test. Each IA study assesses a DMA application bundle prototype and documents the impacts as average speeds, travel time savings, reliability, etc. These are mobility measures used to assess the impacts of the DMA applications. The impacts estimation model uses these inputs to produce nationwide annual impacts over the analysis period.

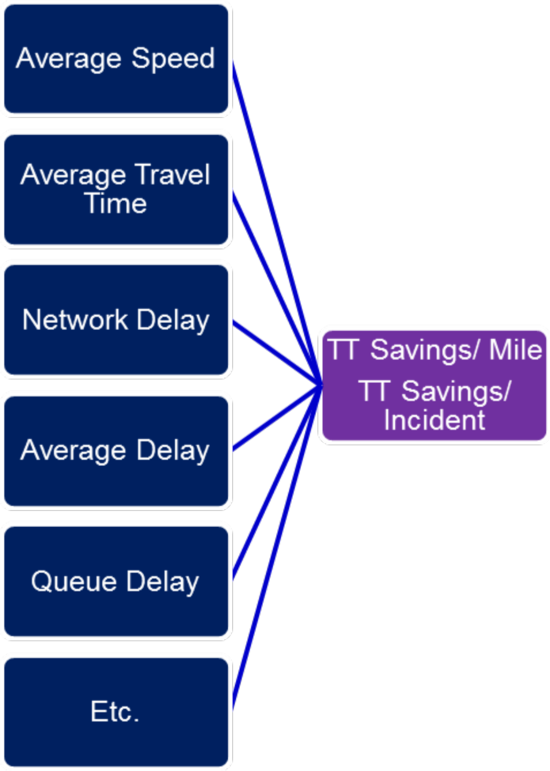
3.3 AMS Testbeds Results

Not all of the IA studies reported impacts as quantified benefits. In those cases, the AMS testbed study results were used for impacts estimation. In this report, the AMS testbed study results were used for FRATIS and EnableATIS bundles.

3.4 Unit Impact Estimation

The unit impact estimation step of the analysis uses results from the IA and PD studies and computes the normalized unit benefits in terms of TT savings/mile or TT savings/incident (for R.E.S.C.U.M.E.). The benefits from the IA projects are normalized to obtain unit benefits, which can then be extrapolated. A representative graphic is shown in Figure 12.

Figure 12. Estimating Unit Benefit in Terms of TT Savings/Unit



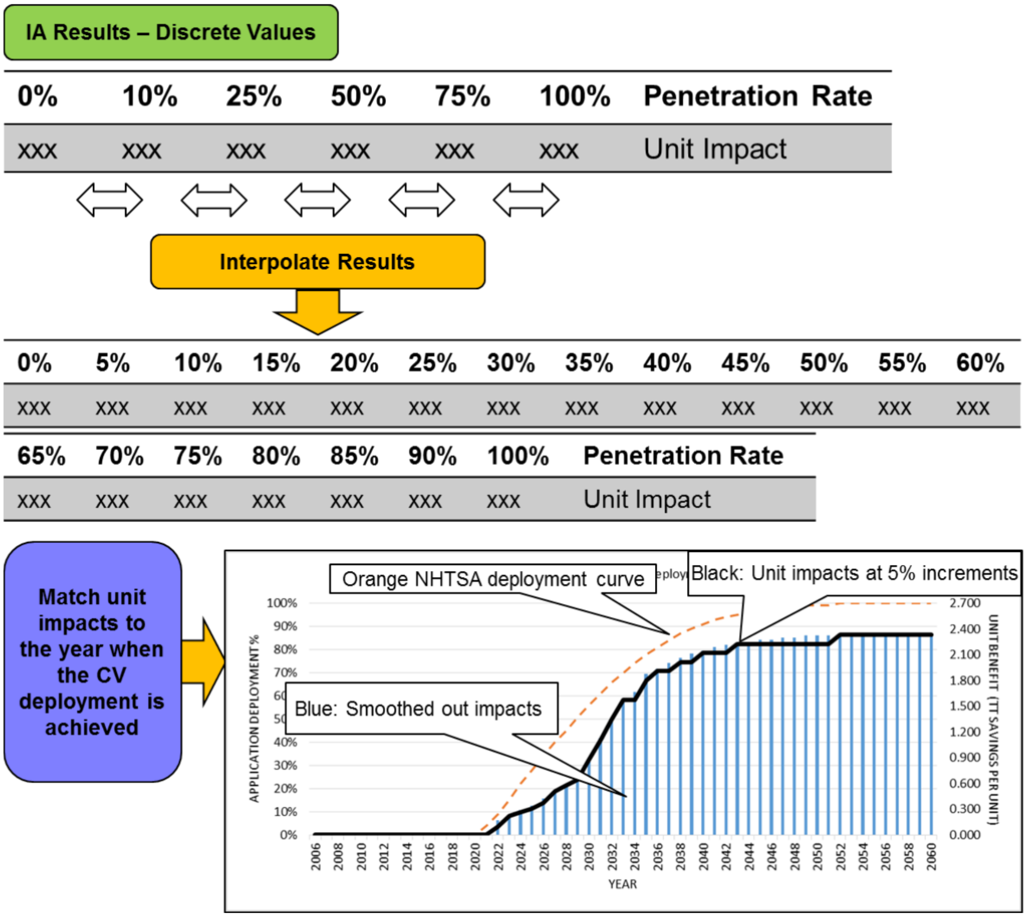
Source: Booz Allen Hamilton, December 2015

3.5 Deployment Rates

The IA results, once normalized, are available as TT savings/unit for discrete CV penetration rates like 0%, 10%, 25%, or 50%. The first step is to interpolate these values to obtain continuous values for every 5% increment in CV penetration rates. The highlighted values are from the IA project and the rest are interpolated values at 5% increments.

The next step is to match these impacts with the year when the corresponding penetration rate is achieved. For example, if a 25% penetration rate is achieved in year 2025 according to the NHTSA deployment curve, the appropriate impact is used for 2025 and so on. The figure below shows the NHTSA deployment curve in orange and the IA results estimated at 5% increments in grey. A smoothed out unit benefit bar chart shows the unit benefit of the INC-ZONE application increasing with growing deployment over the years. These steps are shown in Figure 13.

Figure 13. Impact Estimation Step Three



0%	10%	25%	50%	75%	100%	Penetration Rate
xxx	xxx	xxx	xxx	xxx	xxx	Unit Impact

0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%
xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

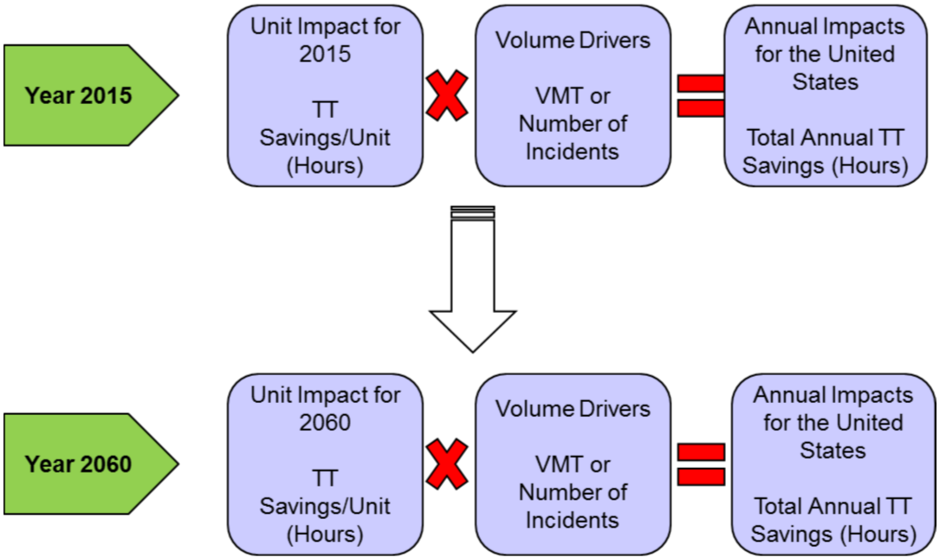
65%	70%	75%	80%	85%	90%	100%	Penetration Rate
xxx	xxx	xxx	xxx	xxx	xxx	xxx	Unit Impact

Source: Booz Allen Hamilton, December 2015

3.6 Extrapolation

The extrapolation step converts the unit benefit into annual quantities for the entire United States for each year of analysis. This step multiplies the unit impacts for each year estimated in the deployment rates step, with the corresponding volume drivers for each application. The extrapolation approach is shown in Figure 14.

Figure 14. Extrapolation of Impacts



Source: Booz Allen Hamilton, December 2015

3.7 Monetization

The monetization step in the impacts estimation process uses the concept of VoT to monetize the annual extrapolated impacts for each year in the analysis period.

Usually, the value of TT is based on the trip purpose, mode, number of passengers, etc., and there are many categories of travel (i.e., business travel, personal travel, recreational travel, interstate travel, and local travel). Since the scope of the project and the availability of nationwide data to classify travel by trip purpose were not available, a general assumption is made to estimate the VoT. The assumption is that the VoT for all light vehicle travel was $12.5 in 2009 ($13.5 in 2012). It is also assumed that the VoT follows the same growth trend as the hourly wages, since hourly wage is one of the factors that is considered while estimating VoT. The VoT for transit trips (per ride for all riders) was $117.76 (2012 dollars), considering Average transit vehicle occupancy is 9.2.[7] The VoT for truck drivers was $24.7 in 2009.

Hourly wage forecasts are part of the baseline development section of this report. The guidance document that was used to determine VoT was generated by the USDOT. It states that 50 to100% of

---

[7] "Transportation Energy Data Book, Edition 34," *U.S. Department of Energy*, September 2015, http://cta.ornl.gov/data/index.shtml.

the income is estimated as VoT. The value $12.5 for all modes in the United States for year 2009 is provided as a recommendation.[8]

These VoT values corresponding to each year are simply multiplied by the total annual impacts (total annual TT Savings in hours) to obtain monetized benefits for each year. All these values are reported as 2012 U.S. Dollars. The monetized results are presented as annual impacts and cumulative impacts for the duration of analysis. No escalation or inflation rates were used to adjust the future values.

Occupancy is a factor that affects the monetization of results. The assumptions related to occupancy are listed below:

- Average vehicle occupancy is 1.69.[9]
- Average transit vehicle occupancy is 9.2.[10]

These factors are used to convert the VMT to person miles traveled or convert the transit trips values to person trips.

3.8 Impact Estimation by Bundle

3.8.1 INFLO

The two applications studied under this bundle were SPD-HARM and Q-WARN. The IA was carried out for these applications jointly since these freeway applications will likely be deployed together for optimal impacts. The INFLO applications, although defined under the mobility umbrella, are largely designed to improve the comfort and safety of freeway travelers.

3.8.1.1 IA Results and Unit Impact Estimation

SPD-HARM and Q-WARN were prototyped on a simulation testbed which was a network from San Mateo, California (CA). The network was 8.5 miles of US-101 Freeway. The test was carried out for five hours, including a PM peak traffic duration. The network had 8 lanes in total with 200,000 to 250,000 Average Annual Daily Traffic (AADT). The free flow speed on the network was 60 miles per hour (mph).

The IA results and some of the simulation parameters are used to estimate the unit benefits of the applications. The INFLO IA test was carried out for 6 scenarios with 0%, 10%, 25%, and 50% CV combined (function of communication loss/latency, market penetration, and driver compliance) rates. The six scenarios were:

---

[8] "The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations, Revision 2," *U.S. Department of Transportation*, September 2011, https://www.transportation.gov/sites/dot.dev/files/docs/vot_guidance_092811c.pdf.

[9] "Summary of Travel Trends: 2009 National Household Travel Survey," *U.S. Department of Transportation*, June 2011, http://nhts.ornl.gov/2009/pub/stt.pdf.

[10] "Transportation Energy Data Book, Edition 34,"*U.S. Department of Energy*, September 2015, http://cta.ornl.gov/data/index.shtml.

1. Dry – no incident with a 79% probability of occurrence
2. Dry – short incident with a 7% probability of occurrence
3. Dry – long incident with a 4% probability of occurrence
4. Rain – no incident with a 8% probability of occurrence
5. Rain – short incident with a 1% probability of occurrence
6. Rain – long incident with a 1% probability of occurrence.

The results were not significant for most scenarios except 1 and 4 (i.e., the impact of the INFLO applications in these scenarios was negligible). Even for scenarios 1 and 4, the results for the 10% penetration rate case were not significant.

TT savings/mile were estimated using the network-wide VHT and VMT values. These were then averaged using the probability of occurrence as weights. The significant results for scenarios 1 and 4 were used to extrapolate TT savings for 75% and 100% CV combined rates. Table 4 shows the TT savings/mile for each level of combined rate.

Table 4. INFLO IA Results Used for Impacts Estimation OSR (only significant results are used from the IA)

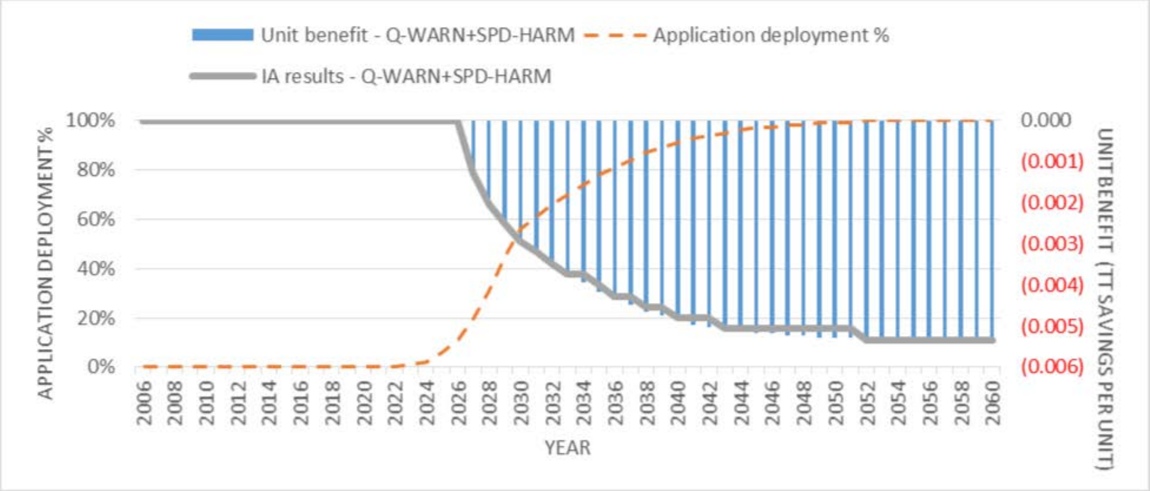
CV Combined Rate	Scenario	VHT (hours)	VMT (miles)	TT Savings/Mile (hours/mile)	TT Savings Weighted Average
0%	Scn 1	6453	275000		0
	Scn 4	9765	275000		
10%	Scn 1	6,050	275000		0
	Scn 4	10,030	275000		
25%	Scn 1	6956	275000	-0.00183	-0.00189
	Scn 4	10450	275000	-0.00249	
50%	Scn 1	7171	275000	-0.00261	-0.00267
	Scn 4	10654	275000	-0.00323	
75%	Scn 1				-0.004
	Scn 4				
100%	Scn 1				-0.00534
	Scn 4				

Source: INFLO IA Report, June 2015

3.8.1.2 Deployment Rates

The impacts matched with the corresponding year that they are expected to be achieved are shown in Figure 15.

Figure 15. Yearly Impacts when the Corresponding CV Deployment Rates are Expected to be Achieved



Source: Booz Allen Hamilton, June 2016

3.8.1.3 Extrapolation

For the INFLO applications, the unit impacts are presented as TT savings/mile of freeway travel. In order to extrapolate them to obtain nationwide annual impacts, they are multiplied by their volume driver (i.e., VMT on freeways). The extrapolated impacts of INFLO applications may have been exaggerated in this analysis since the Q- WARN and SPD-HARM applications are only activated under certain circumstances (e.g. a slowdown and/or queue has formed downstream). However, to offset this exaggeration to some extent, the TT savings were calculated using the VHT and VMT values for all the vehicles in the simulation, for the entire duration of the simulation period. To some extent, this approach captures the generalized impacts on a section of a network brought about by INFLO applications.

3.8.1.4 Monetization and Results

The extrapolated annual impacts are multiplied by the VoT. The results are presented as annual and cumulative charts in Figure 16.

Although the results are all negative, it does not mean that the applications will have disbenefits or losses. These estimations are all based on mobility measures only. They do not consider safety or environmental impacts, which may be notable as reported in the IA study.[11]

The IA study notes that the tradeoff for the safety benefits of SPD-HARM/Q-WARN is slightly lower average speeds on the freeway under all scenarios. The effect is linear between 0%, 10%, 25%, and 50% vehicles.

The number of lane changes per thousand vehicles, another indirect indicator of safety effects, increases with increasing penetration rate. However, the effect of SPD-HARM on reducing the speed differential between vehicles may facilitate more and safer lane changes. Therefore, the increase in lane changing may not be a 100% adverse indicator of safety when SPD-HARM is implemented.

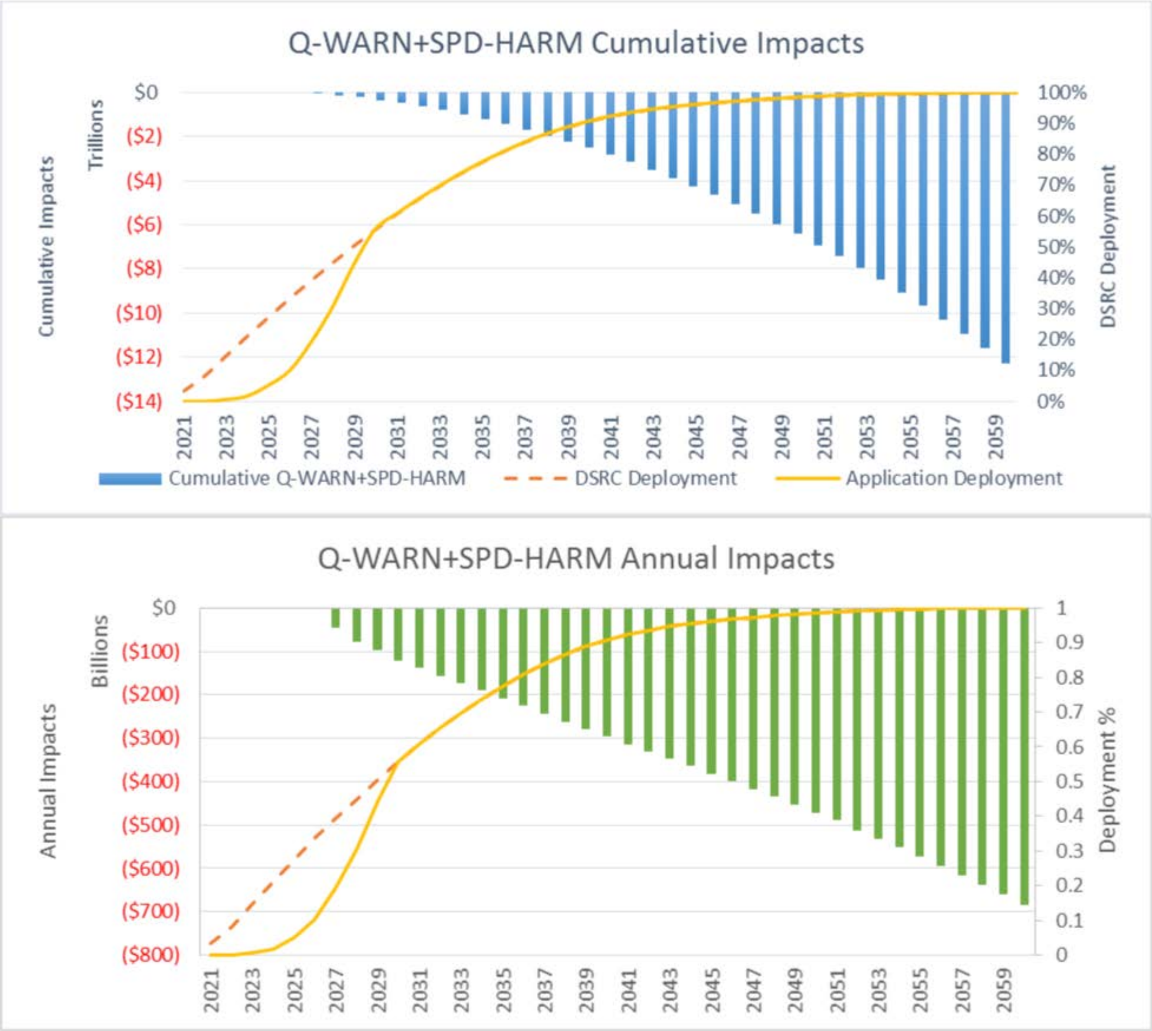
The percentage of affects the predicted annual reduction in speed differentials between freeway segments (interlink shockwaves) and within freeway segments (intra-link shockwaves). These are both desirable safety benefits that may lead to a reduction in rear-end crashes and also reduce the fuel consumption (attributable to fewer speed transitions).

The estimates provided here are not costs that will be incurred by the government or the state and local agencies. They are an indicator that there are some negative disbenefits in terms of mobility (i.e., travel time savings) that may result from the INFLO applications. In the future, there is a possibility that the safety benefits (i.e., reduction in crashes) may negate some of the disbenefits due to increased travel times.

---

[11] "Impacts Assessment of Dynamic Speed Harmonization with Queue Warning Task 3 IA Report Version 3.1," *U.S. Department of Transportation*, June 2015.

Figure 16. Cumulative and Annual Monetized Mobility Impacts for SPD-HARM and Q-WARN



Source: Booz Allen Hamilton, June 2016

3.8.2 MMITSS

3.8.2.1 IA Results and Unit Impact Estimation

The MMITSS study was carried out for the I-SIG, TSP, and FSP applications. These applications are designed to improve the signal operations on arterials. The IA report was the source for the unit impact estimates used in this study.[12]

All the studies in the IA were carried out on a Virginia simulation testbed, an Arizona simulation testbed, and an Arizona field test. For the impacts estimation, the results from the Phoenix, Arizona, simulation testbed are used. The Arizona testbed is an arterial section 1.9 miles in length with 3 lanes in each direction. There are six signalized intersections on the network. It has a saturation flow rate of 1,800 vehicles per hour per lane (veh/hr/lane) and a free flow speed of 40 mph. Morning peak period demands in the Arizona test corridor produced V/C equal to 0.5, indicating that test intersections were operating under capacity, with no excessive delays. The benefits are quantified using the HPI data table on Annual VMT from 2010. The simulation results were used instead of the field test because the field test was a very controlled test with few test vehicles. The simulation test was a better representation of the applications.

The baseline TT/mile was 0.0329 hours/mile. Table 5 shows the unit benefits calculated from the IA results for the I-SIG application. The value for 100% penetration rate is extrapolated from the results.

Table 5. IA Results and Unit Impacts for I-SIG from the AZ Testbed for V/C Ratio 0.5

CV Penetration	VHT	VMT	TT savings/mi
0%	133.7	4056.925	0.00000
25%	133.73490	4056.925	0.00134
50%	132.2368	4056.925	0.00172
75%	133.0688	4056.925	0.00152
100%	133.01350	4056.925	0.00161

Source: MMITSS IA Report, August 2015

Table 6 shows the results for the TSP and FSP applications that were used as unit benefits. These were estimated for transit and freight vehicles in the network. It was assumed that all the transit and freight vehicles were equipped in the simulation study. For the impacts estimation, TT savings were estimated for penetration levels below 100%.

---

[12] "Multi Modal Intelligent Traffic Signal Systems Impacts Assessment Final Report," *U.S. Department of Transportation*, August 2015.

Table 6. IA Results and Unit Impacts for TSP and FSP from the AZ Testbed for V/C Ratio 0.5

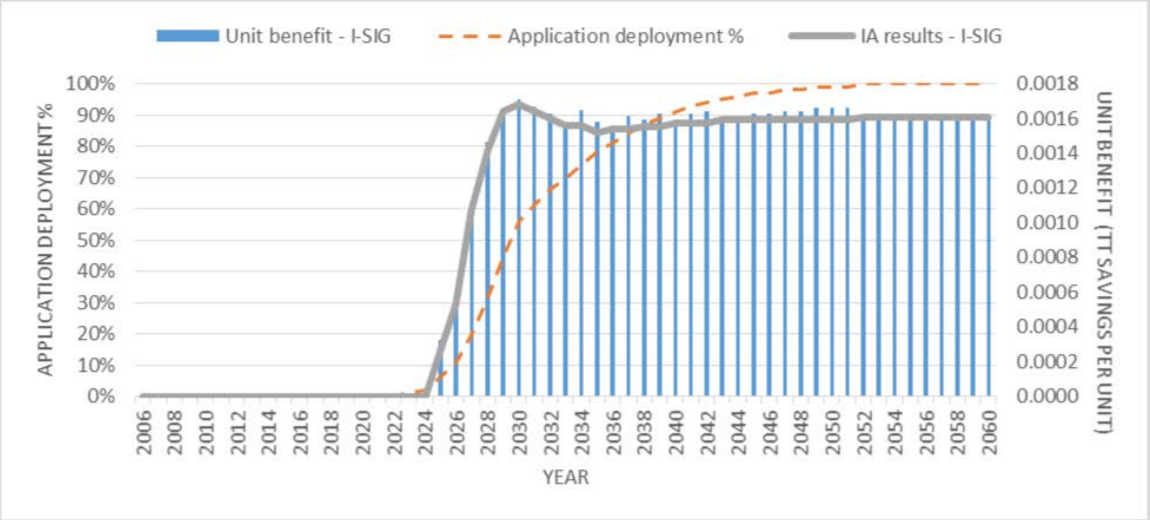
TSP (TT savings/mile)	FSP (TT savings/mile)
0.00526	0.00584
(Estimated from average TT savings for transit vehicles in the network)	(Estimated from average TT savings for freight vehicles in the network)

Source: Booz Allen Hamilton, June 2016

3.8.2.2 Deployment Rates

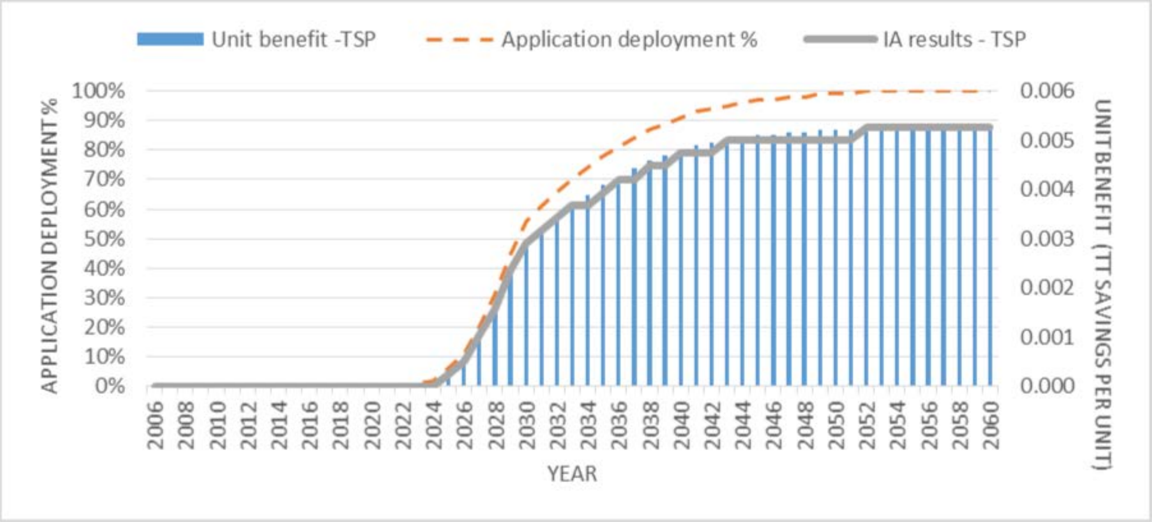
The unit impacts matched with the corresponding year in which they are expected to be achieved for the I-SIG application are shown in Figure 17. TSP and FSP unit impacts are shown in Figure 18 and Figure 19, respectively.

Figure 17. Impacts Matched with the Years when the Corresponding CV Penetration Rates are Expected to be Achieved for the I-SIG Application



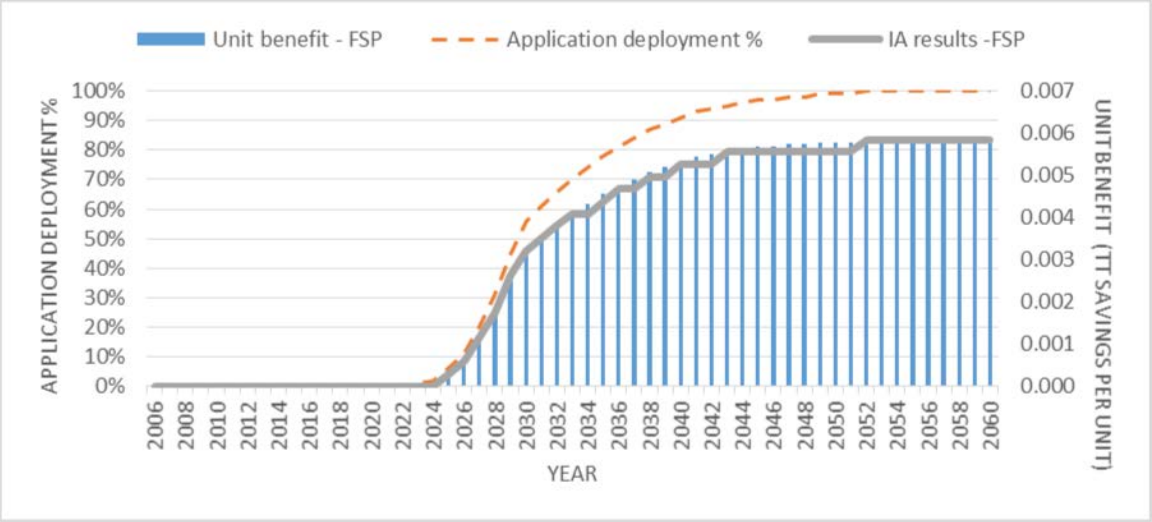
Source: Booz Allen Hamilton, June 2016

Figure 18. Impacts Matched with the Years when the Corresponding CV Penetration Rates are Expected to be Achieved for the TSP Application



Source: Booz Allen Hamilton, June 2016

Figure 19. Impacts Matched with the Years when the Corresponding CV Penetration Rates are Expected to be Achieved for the FSP Application



Source: Booz Allen Hamilton, June 2016

3.8.2.3 Extrapolation

For the MMITSS applications, the unit impacts are presented as TT savings/mile of arterial travel. In order to extrapolate them to obtain nationwide annual impacts, they are multiplied by their volume driver (i.e., VMT on arterials).

Using the highway policy information data table on annual VMT from 2010,[13] it is estimated that the percentage of transit vehicle miles traveled on arterials is 0.464 percent of the total VMT, and the freight vehicle miles traveled on arterials is 7.995 percent of the total VMT.

3.8.2.4 Monetization and Results

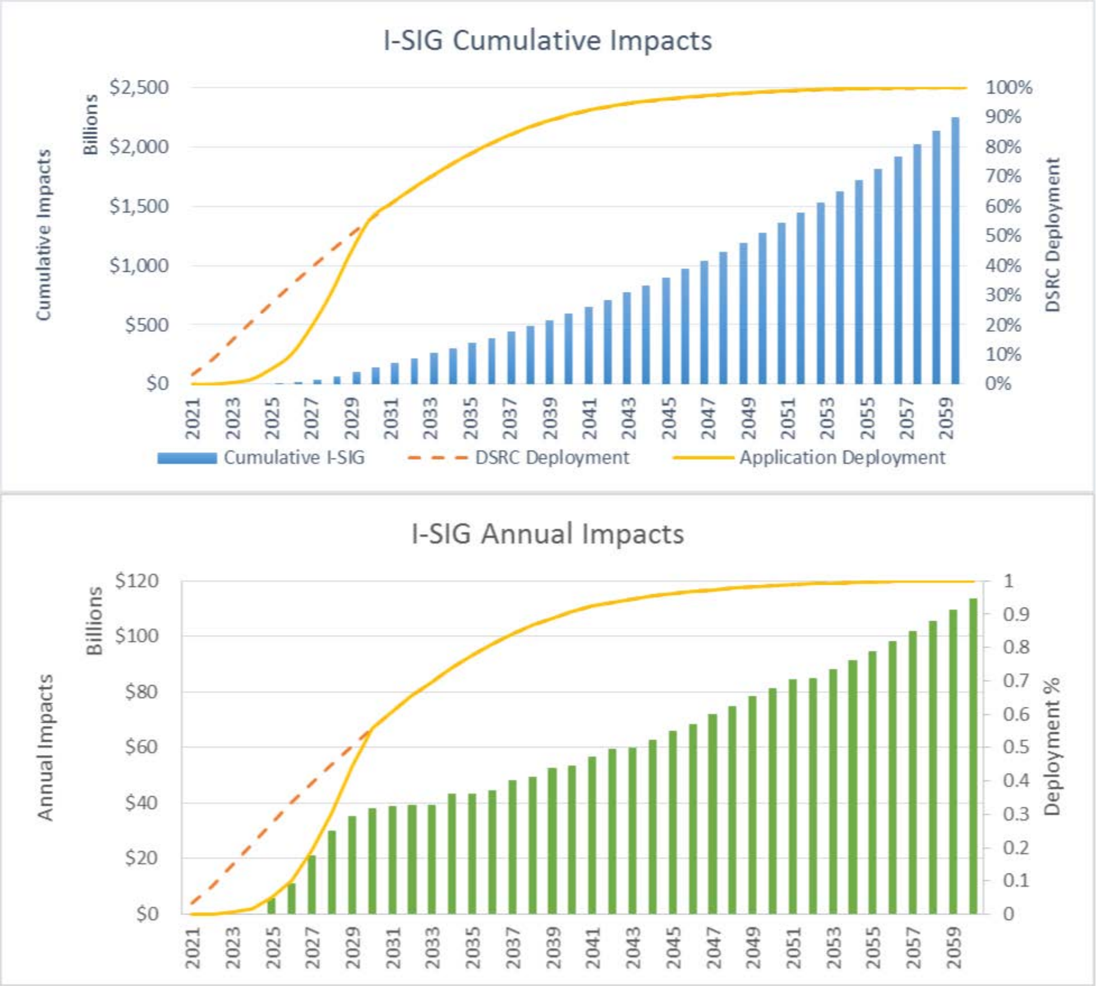
The extrapolated annual mobility impacts are multiplied by the VoT to obtain monetized impacts.

The results for I-SIG are presented as annual and cumulative charts in Figure 20. The annual impacts grow aggressively between 25% and 50% penetration rates, which are achieved between years 2027 and 2033. This is attributed to the fact that the unit benefits between 25% and 50% deployment exhibit an increasing trend and then decrease slightly between 50% to 75% deployments. This is exaggerated further by the fact that the deployment rates between years 2027 and 2033 is quite aggressive. The growth of arterial VMT over the years also contributes to the increase in annual impacts along with the increasing benefit with higher penetration rates in the future years.

---

[13] "Annual Vehicle Distance Traveled in Miles and Related Data – 2012 (1) By Highway Category and Vehicle Type," *U.S. Department of Transportation*, January 2014, https://www.fhwa.dot.gov/policyinformation/statistics/2012/pdf/vm1.pdf.

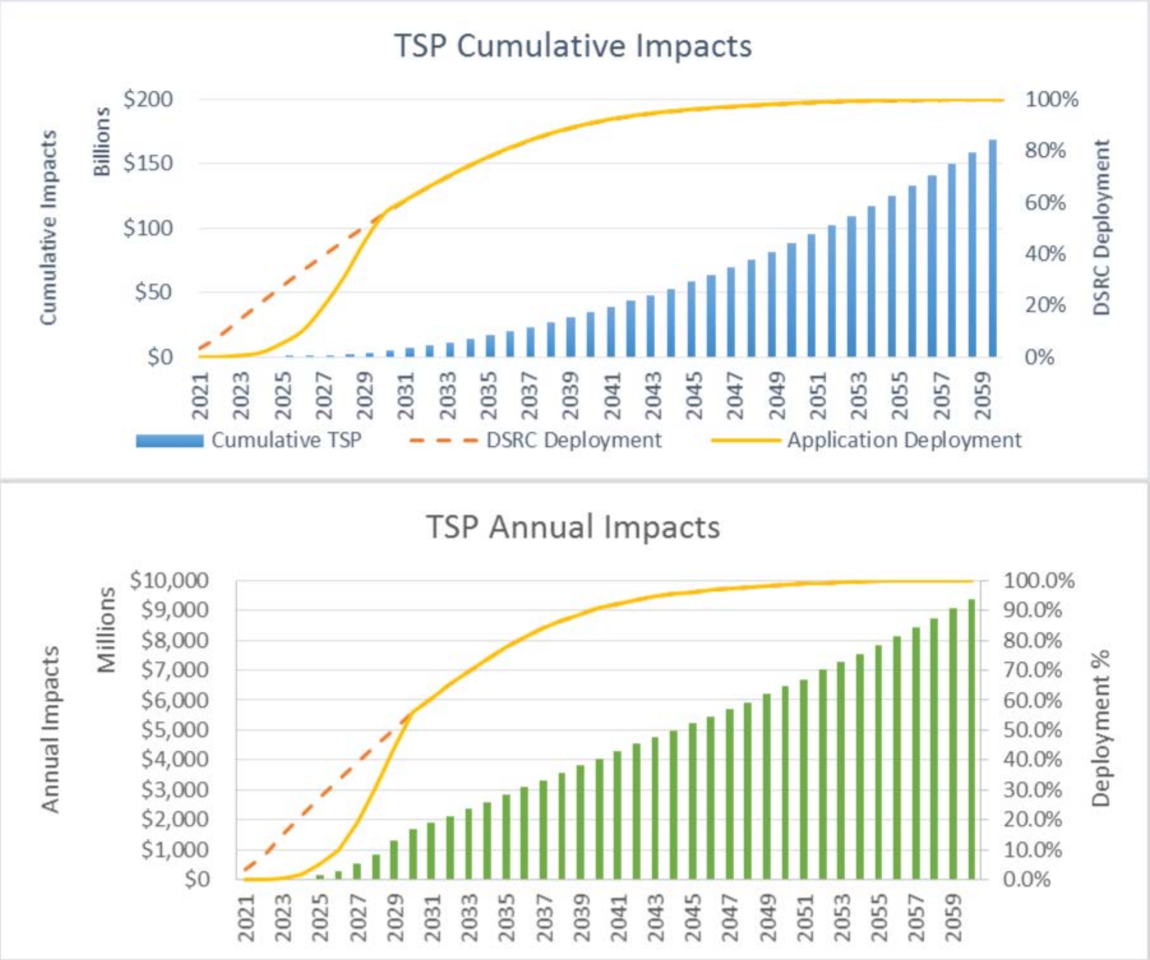
Figure 20. Cumulative and Annual Monetized Mobility Impacts for I-SIG



Source: Booz Allen Hamilton, June 2016

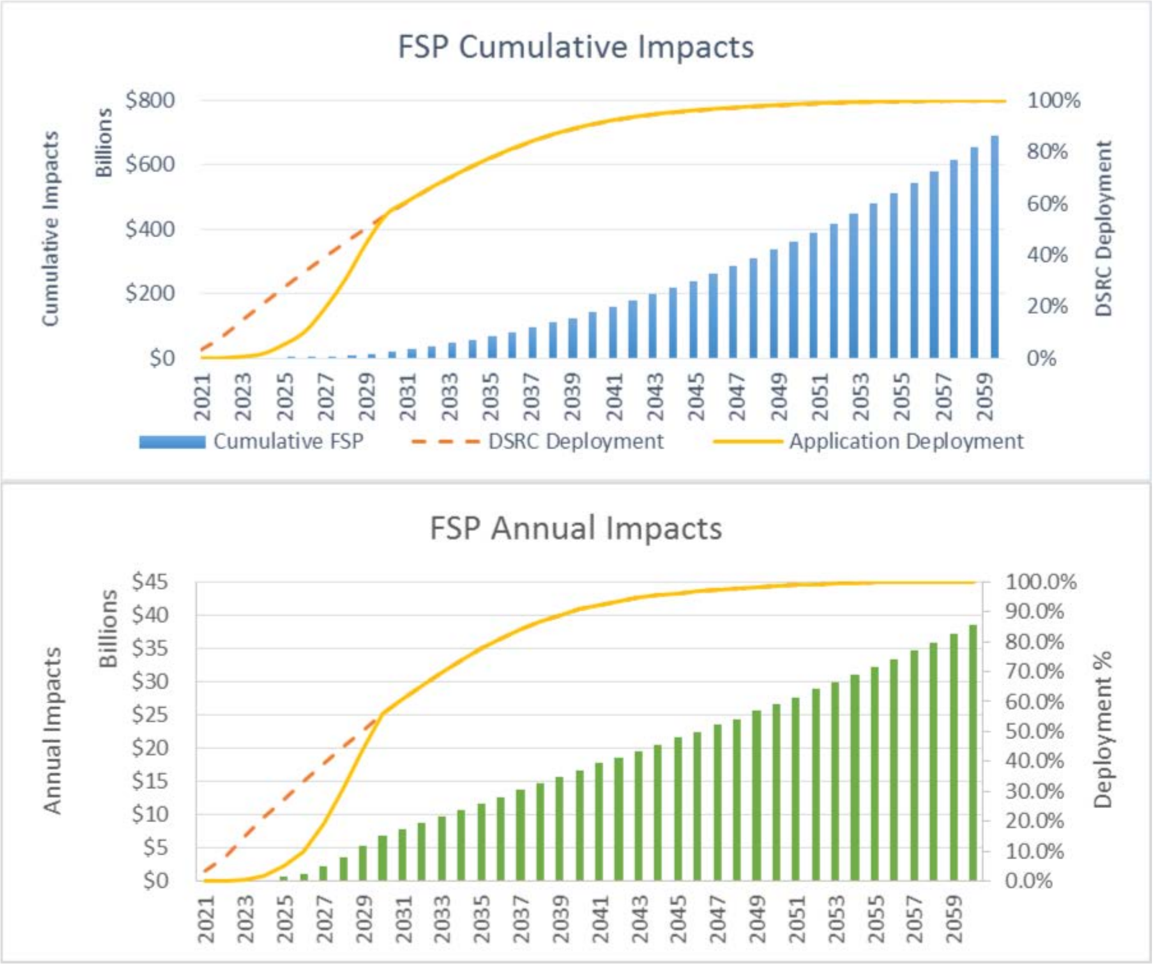
Figure 21 and Figure 22 show the TSP and FSP impacts. The figures show that they both follow a similar trend. However, these impacts are smaller than other applications like I-SIG since these are designed to benefit the transit and freight vehicles only. Additional benefits may be derived from vehicles experiencing lower travel time delays when the priority phases are activated. There may also be disbenefits from vehicles incurring delays on side streets where the priority phases are not implemented.

Figure 21. Cumulative and Annual Monetized Mobility Impacts for TSP



Source: Booz Allen Hamilton, June 2016

Figure 22. Cumulative and Annual Monetized Mobility Impacts for FSP



Source: Booz Allen Hamilton, June 2016

3.8.3 R.E.S.C.U.M.E.

3.8.3.1 IA Results and Unit Impact Estimation

The R.E.S.C.U.M.E. IA study captured the mobility impacts for the INC-ZONE application. The IA was carried out using data from RITIS (Regional Integrated Transportation Information System) and simulation results. The results used for the national extrapolation are for dry conditions. The travel times were estimated using the increase in average speed on the roadway with incidents. The average increase in sub link speed at 100% penetration was found to be 14% in the simulation. These increases in speed reduced the travel time through the incident zones resulting in TT savings for the vehicles passing through the zones during the incident. The IA's regional extrapolation was carried out using incident data from a full year on the I-495 freeway in the National Capital Region. Results from the IA for penetration rates 10%, 25%, 50%, 75%, and 100% were used. Table 7 shows the unit benefit results that were used as inputs for estimating the impacts of INC-ZONE.[14] The unit benefits apply for all vehicles that pass the incident scene, within the reported duration of the incident. The TT savings in the IA were computed for R.E.S.C.U.M.E. using the RITIS data for incidents. In order to compute the actual TT savings/incident values and not TT savings percentages, additional information like VHT, VMT, and travel times were requested from the IA team.

Table 7. Unit Mobility Benefits Used for the INC-ZONE Application

CV penetration	**10%**	**25%**	**50%**	**75%**	**100%**
TT savings (hours) /incident on freeway	0.185	0.302	0.647	1.805	2.334

Source: R.E.S.C.U.M.E. IA Report, April 2015

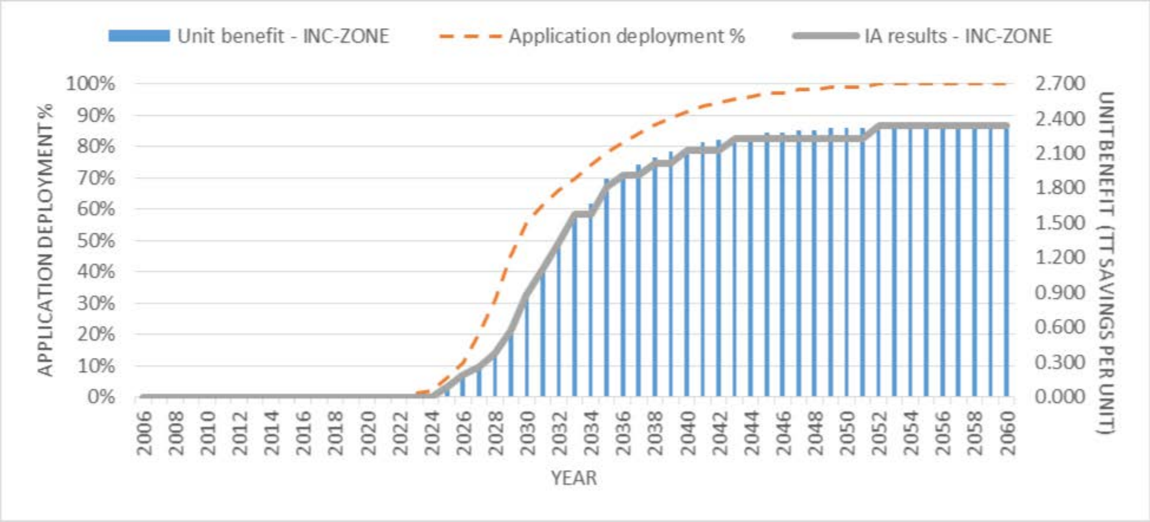
3.8.3.2 Deployment Rates

Figure 23 depicts the impacts and the corresponding year that these impacts are expected to be achieved.

---

[14] "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), Final Report," *U.S. Department of Transportation*, May 8, 2015.

Figure 23. INC-ZONE Mobility Impacts Matched with the Years when the Corresponding CV Penetration Rates are Expected to be Achieved



Source: Booz Allen Hamilton, June 2016

3.8.3.3 Extrapolation

For the INC-ZONE application, the unit impacts are presented as TT savings/incident on freeways. In order to extrapolate them to obtain nationwide annual impacts, they are multiplied by their volume driver (i.e., the number of incidents on freeways across the country). The IA results were used as the basis for extrapolation. The R.E.S.C.U.M.E. IA carried out a regional extrapolation using multiple incident durations using the RITIS data for I-495 (capital beltway) over an entire year. This consisted of several different types of incidents.[15]

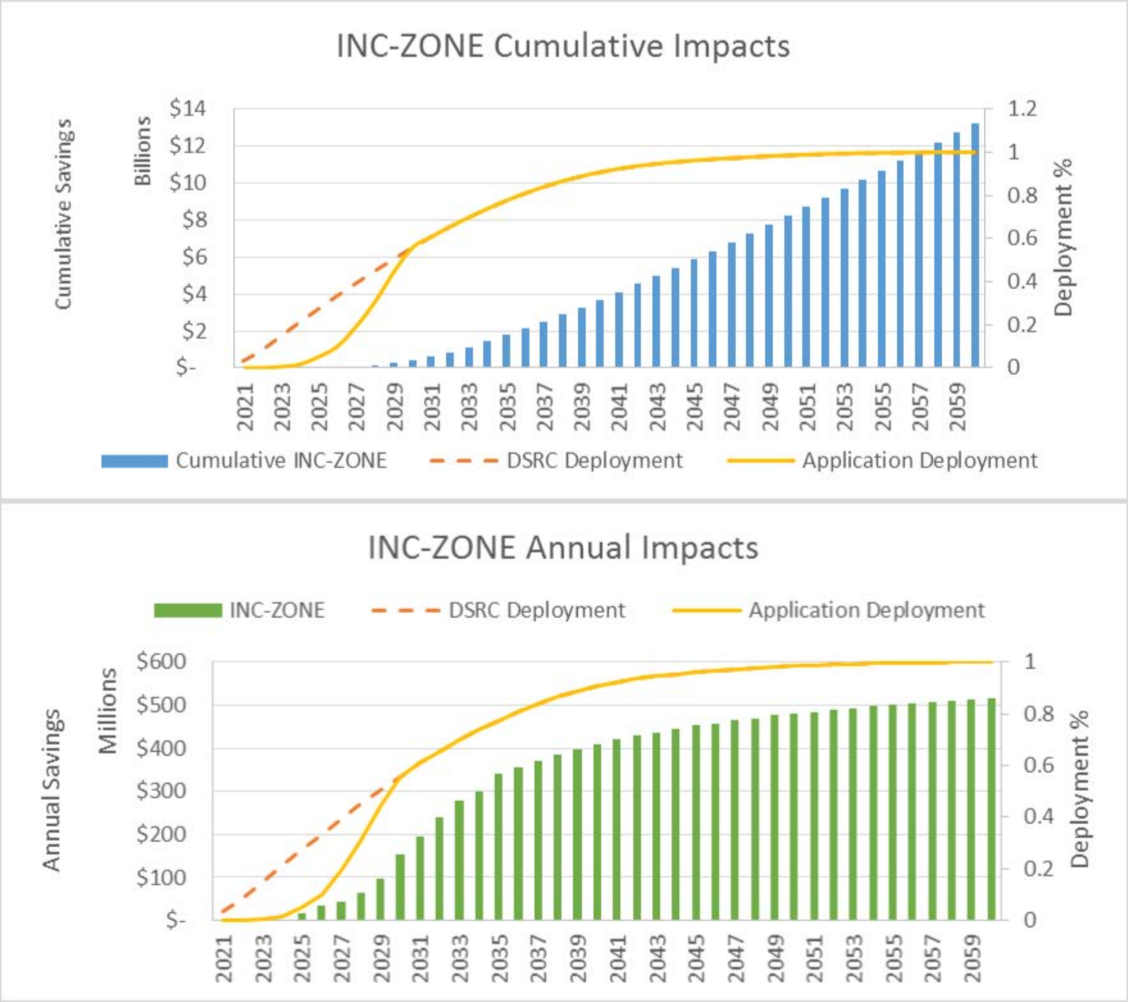
3.8.3.4 Monetization and Results

The extrapolated annual impacts are multiplied by VoT. The monetized annual and cumulative impacts for INC-ZONE are shown in Figure 24. The annual impacts follow a trend similar to the application deployment curve. This indicates that the benefits of the application increase with higher penetration. The cumulative benefits increase linearly over the years.

---

[15] "R.E.S.C.U.M.E. IA Report (INC-ZONE & RESP-STG)," *U.S. Department of Transportation,* April 2015.

Figure 24. Cumulative and Annual Monetized Mobility Impacts for INC-ZONE



Source: Booz Allen Hamilton, December 2015

3.8.4 EnableATIS

3.8.4.1 AMS Testbed Results and Unit Impact Estimation

The AMS Testbed study captured the mobility impacts for the EnableATIS application. The Phoenix testbed was used to carry out the study. EnableATIS in essence provided time-dependent shortest path from origin to destination for travelers (pre-trip planning) or from the current location to destination (en-route rerouting). On a calibrated Phoenix network in a transportation planning tool called DTALite, several scenarios of non-recurrent congestion and means of providing information pre-trip or en-route were implemented. Travelers without EnableATIS selected routes according to the traffic condition.

When non-recurrent bottlenecks according to the incidents/accidents log from Arizona DOT on the corresponding day were simulated, real-time traffic change information was provided to the simulated travelers with EnableATIS. Table 8 provides the estimated unit benefits for the corresponding application deployment rates.

Table 8. Unit Mobility Benefits Used for the EnableATIS Application

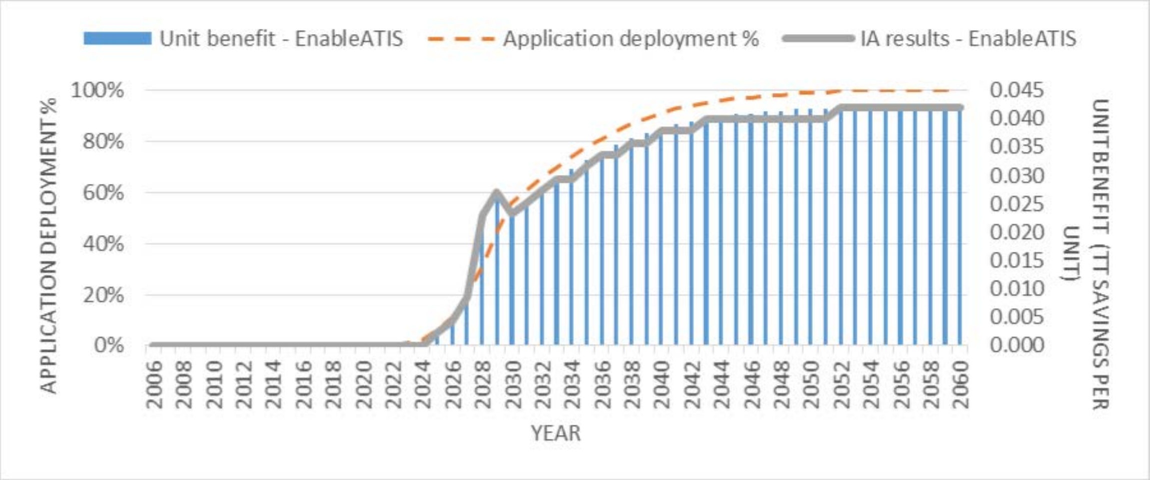
CV Penetration	20%	25%	35%	40%	45%	55%
TT Savings hours/mile	0.00852715	0.01830964	0.0229964	0.0259751	0.02887715	0.02696113

Source: Booz Allen Hamilton, June 2016

3.8.4.2 *Deployment Rates*

The impacts matched with the corresponding year in which they are expected to be achieved are shown in Figure 25.

Figure 25. EnableATIS Mobility Impacts Matched with the Years when the Corresponding CV Penetration Rates are Expected to be Achieved



Source: Booz Allen Hamilton, December 2015

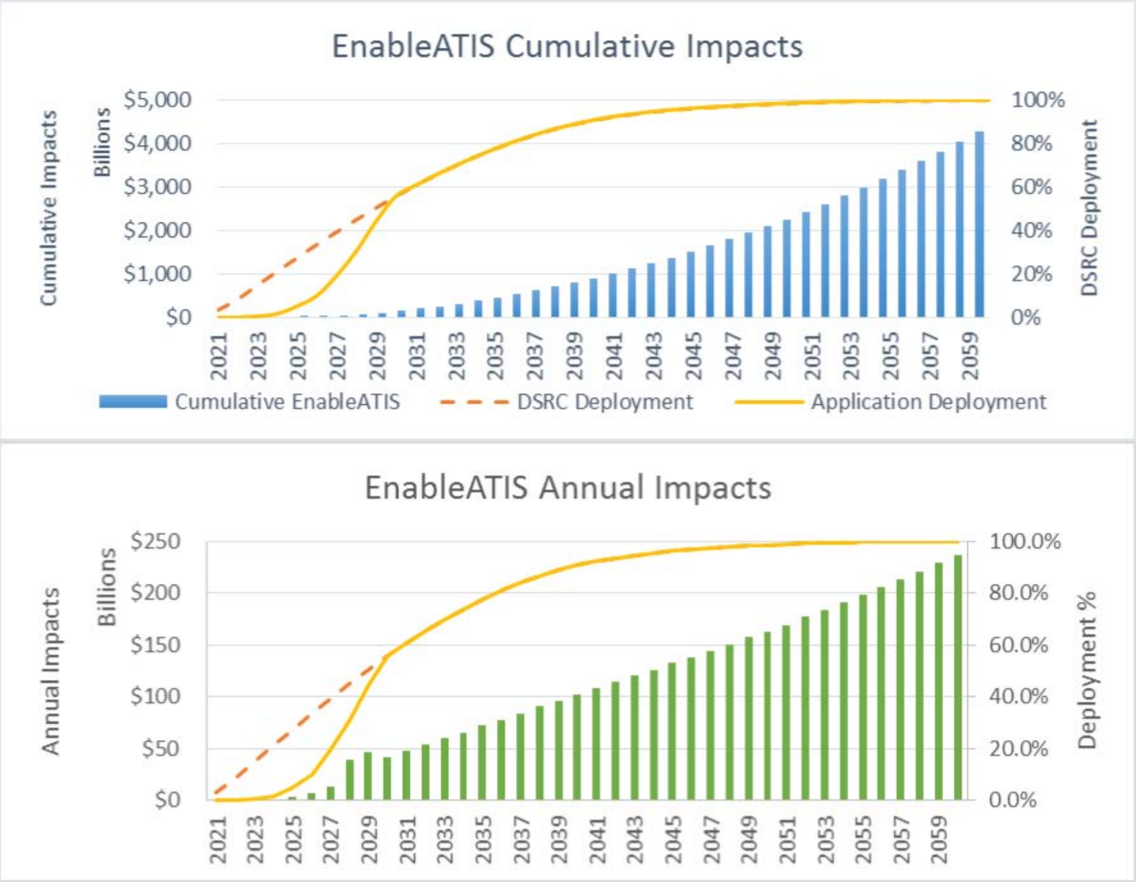
3.8.4.3 *Extrapolation*

For EnableATIS, the unit impacts are presented as TT savings/mile on arterials and local roads. Since the AMS testbed only modeled an urban area, impacts on the freeways are not considered in the impacts estimation. The volume driver for the application is VMT on arterials and locals.

3.8.4.4 Monetization and Results

The extrapolated annual impacts are multiplied by VoT. The monetized annual and cumulative impacts for EnableATIS are shown in Figure 26. The annual impacts follow a trend similar to the application deployment curve. This indicates that the benefits of the application increase with higher penetration. The cumulative benefits increase linearly over the years.

Figure 26. Cumulative and Annual Monetized Mobility Impacts for EnableATIS



Source: Booz Allen Hamilton, June 2016

3.8.5 FRATIS

3.8.5.1 AMS Testbed Results and Unit Impact Estimation

Table 9 shows the unit benefit results that were used as inputs for estimating the impacts of FRATIS. The AMS testbed team did not implement various CV penetration rates for the FRATIS application. In order to compute the actual TT savings/incident values and not TT savings percentages, additional information like VHT, VMT, and travel times were requested from the AMS testbeds team.

The FRATIS bundle in the AMS testbeds study was designed to provide trip information, drayage optimization, and route guidance to trucks. The application bundle was simulated on a Phoenix network in a tool called DTALite. The experiment consisted of three trucks that had FRATIS application enabled. They left from three different warehouses and made three delivery stops each. They traversed in regular traffic conditions with simulated bottlenecks.

Table 9. Unit Mobility Benefits Used for the FRATIS Application

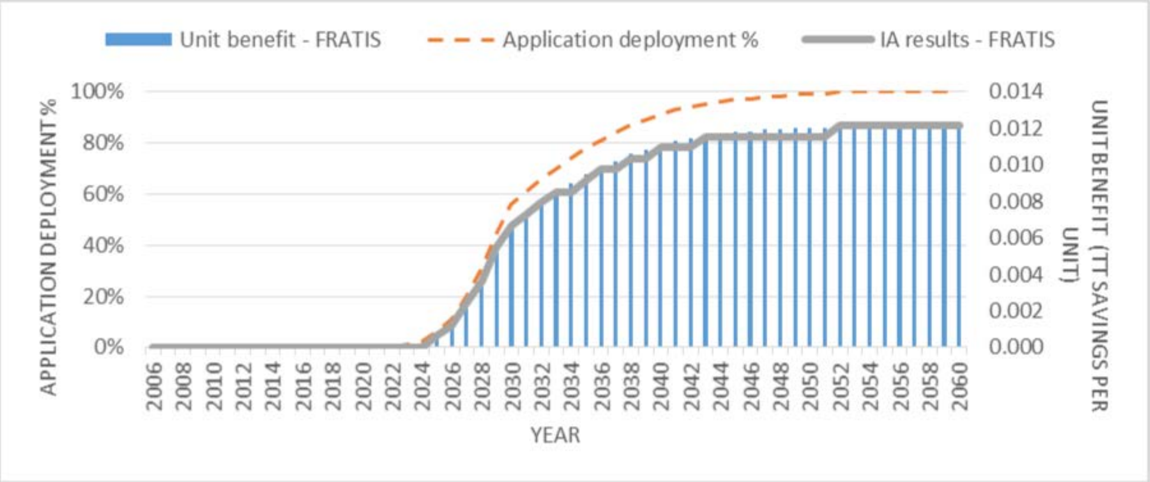
CV Penetration	100%
TT Savings (hours) /truck mile on arterials and locals	0.0121

Source: Booz Allen Hamilton, June 2016

3.8.5.2 Deployment Rates

The impacts matched with the corresponding year in which they are expected to be achieved are shown in Figure 27.

Figure 27. FRATIS Mobility Impacts Matched with the Years when the Corresponding CV Penetration Rates are Expected to be Achieved



Source: Booz Allen Hamilton, June 2016

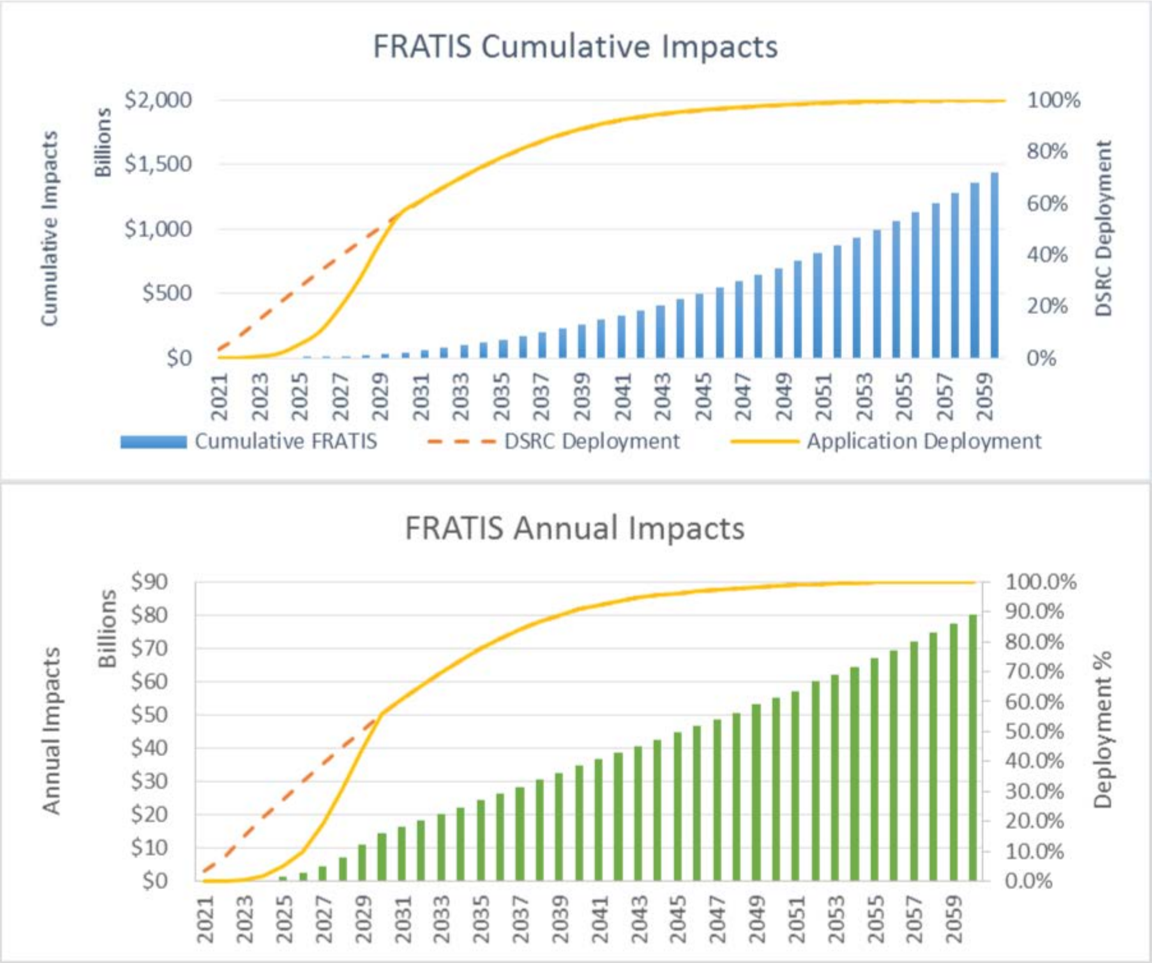
3.8.5.3 Extrapolation

The FRATIS application is extrapolated using the truck VMT on arterials and locals. The impacts of the FRATIS application on non-truck traffic was not captured in this study.

3.8.5.4 Monetization and Results

The extrapolated annual impacts are multiplied by VoT for Truck drivers, which is higher than for passenger cars. The monetized annual and cumulative impacts for FRATIS are shown in Figure 28. The annual impacts follow a trend similar to the application deployment curve. This indicates that the benefits of the application increase with higher penetration. The cumulative benefits increase linearly over the years.

Figure 28. Cumulative and Annual Monetized Mobility Impacts for FRATIS



Source: Booz Allen Hamilton, June 2016

3.8.6 IDTO

3.8.6.1 IA Results and Unit Impact Estimation

The IDTO IA team used results from the prototype demonstrations of the IDTO applications in Columbus and the Central Florida region. In order to augment the analysis of the demonstrations, the IA team conducted in-depth interviews with entities providing unique demand-response transportation services to learn more about the impacts of their services. An analytical statistical tool, known as the Integrated Dynamic Transit Operations – Bundle Evaluation Tool (IDTO-BET), was developed to simulate the functions of IDTO.

Table 10. Unit Mobility Benefits Used for the IDTO Applications

CV Penetration	T-CONNECT 100%	T-DISP 100%
TT Savings/Transit Trip	2.716	1.45

Source: IDTO IA Report, January 2016

3.8.6.2 Deployment Rates

The impacts matched with the corresponding year in which they are expected to be achieved are shown in Figure 29. The T-DISP application provides slightly higher benefits as compared to T-CONNECT.

Figure 29. T-DISP and T-CONNECT Mobility Impacts Matched with the Years When the Corresponding CV Penetration Rates are Expected to be Achieved

Source: Booz Allen Hamilton, June 2016

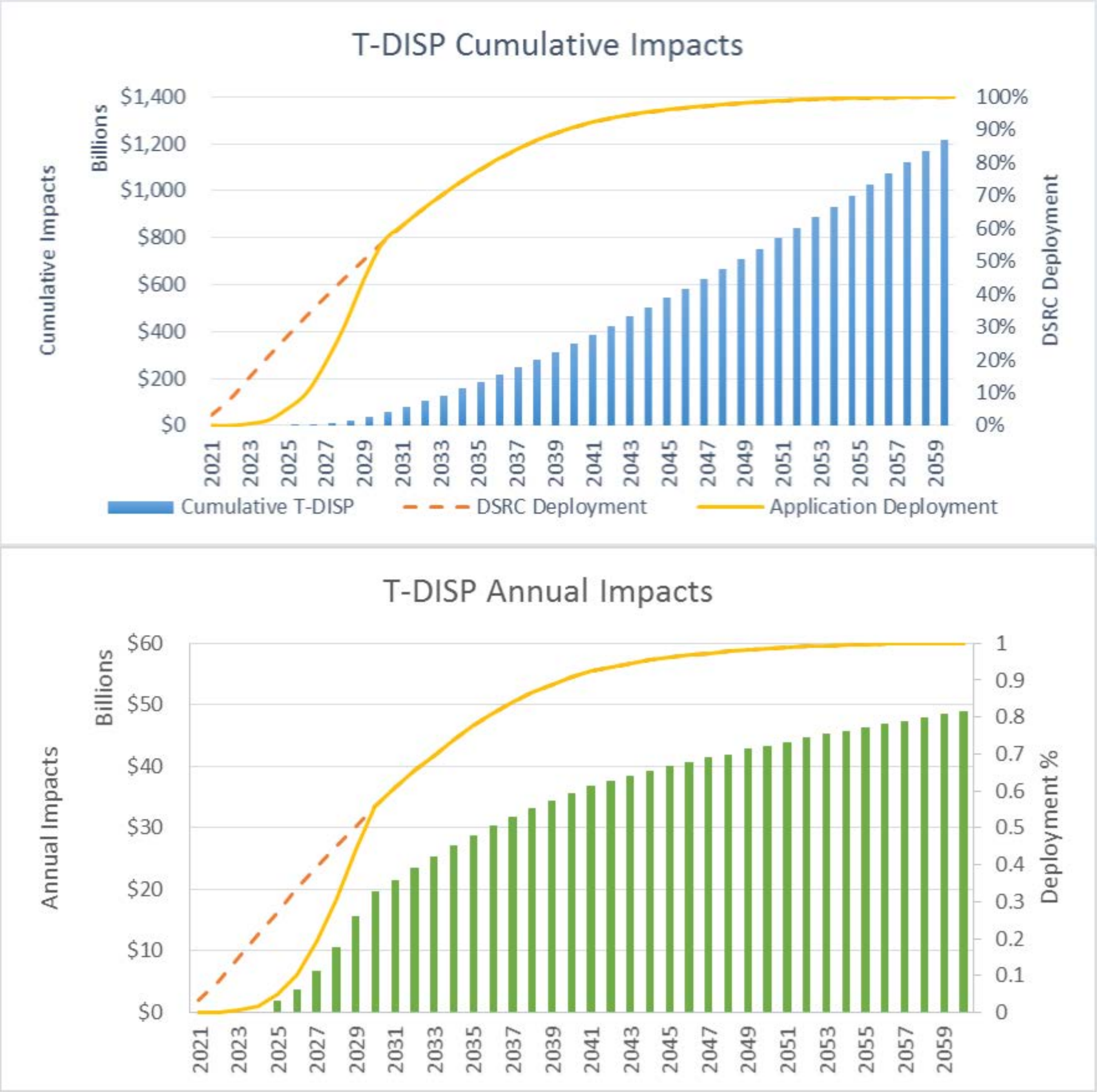
3.8.6.3 Extrapolation

For the IDTO applications, the unit impacts are presented as TT savings/transit trip. In order to extrapolate them to obtain nationwide annual impacts, they are multiplied by their volume driver (i.e., the number of transit rides across the country and the average occupancy of transit vehicles). The IA results were used as the basis for extrapolation.

3.8.6.4 *Monetization and Results*

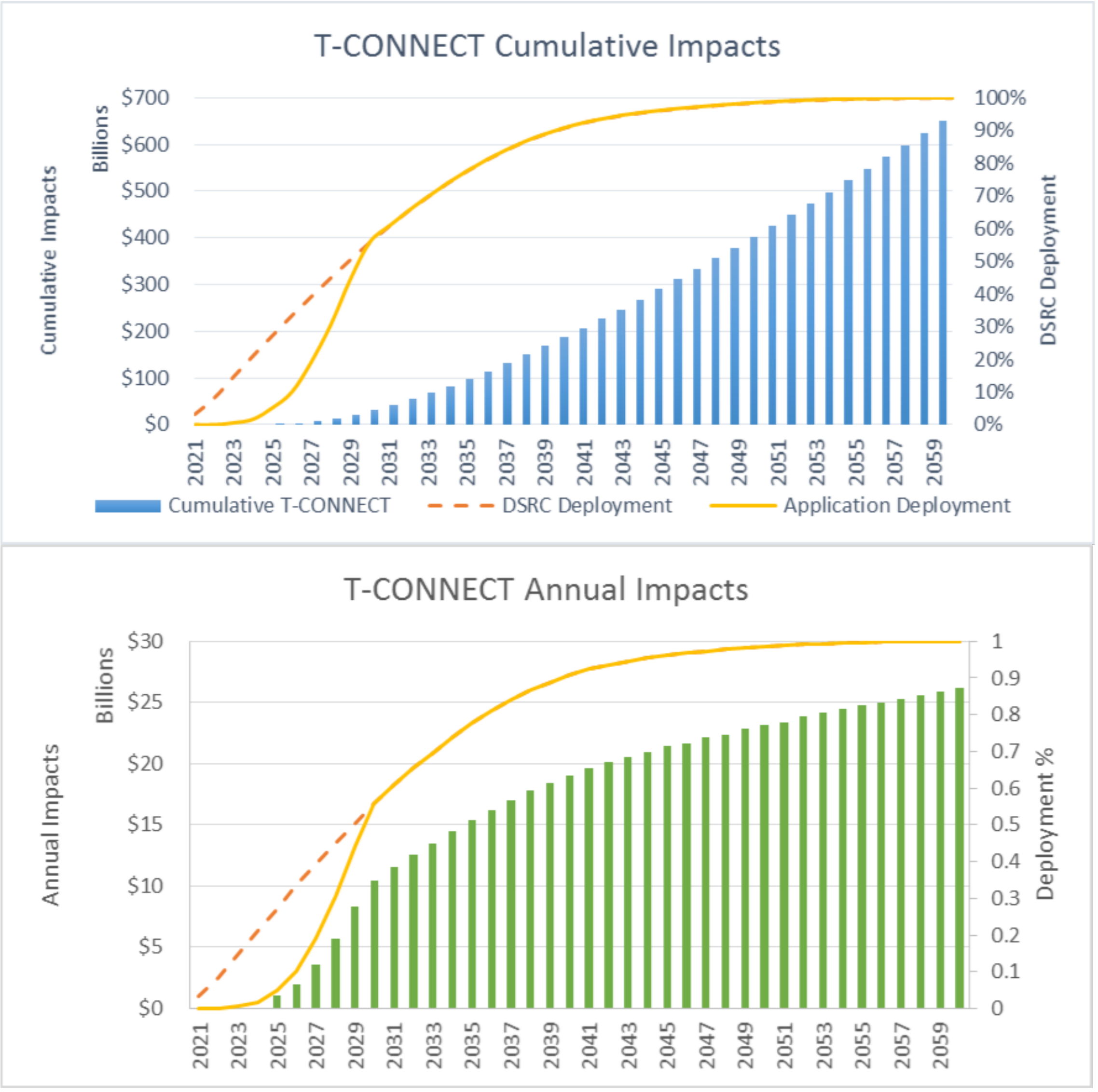
The extrapolated annual impacts are multiplied by VoT for transit riders. The monetized annual and cumulative impacts for the IDTO applications are shown in Figures 30 and 31. The annual impacts follow a trend similar to the application deployment curve. This indicates that the benefits of the application increase with higher penetration. The cumulative benefits increase linearly over the years.

Figure 30. Cumulative and Annual Monetized Mobility Impacts for T-DISP



Source: Booz Allen Hamilton, June 2016

Figure 31. Cumulative and Annual Monetized Mobility Impacts for T-CONNECT



Source: Booz Allen Hamilton, June 2016

Chapter 4. Cost Estimation

4.1 Overview of the Approach

Booz Allen's cost estimating team used a bottom-up estimating approach to develop a discrete estimate for each cost element within the cost breakdown structure (CBS) and rolled up these lower-level elements to achieve an estimate for the deployment of each application at the national level. As stated in the Introduction section, six bundles of applications are evaluated under this task. The cost estimation has been carried out for the same set of applications from which the team received the AMS testbed's IA and simulation results.

The cost estimation started by identifying a comprehensive cost breakdown structure and mapping applicable cost elements to each DMA application. These cost elements were then categorized, estimated, and extrapolated to the national level based on the NHTSA's least aggressive safety application deployment rate for each application from year 2021 through year 2060. The detailed cost estimation assumptions, data sources, methodology, and final results are described in the following sections of the report. Many applications share similar cost elements, and this analysis has considered cost sharing opportunities while calculating the total cost of deploying each individual application.

The AASHTO Life Cycle Cost (LCC) model was used as the basis for the DMA national level cost estimation effort. The AASHTO LCC model is a tool designed to provide CV deployment agencies and organizations with a method to estimate V2I application implementation costs. The LCC model uses the CO-PILOT tool as its basis for constructing the cost breakdown structure (CBS) (i.e., building blocks) and unit costs. In the AASHTO LCC tool, the agency is asked to answer a series of questions regarding quantities of specific components required for their anticipated application to deploy. These quantities are used as multipliers in that model to estimate the total deployment cost of each application over the next 40 years.

4.2 Cost Estimation Assumptions

Ground Rules and Assumptions for Cost Estimation: The purpose of establishing ground rules and assumptions for the cost estimation analysis is to provide visibility into the cost estimation methodology which was used to develop each of the application-specific estimates within certain parameters and boundaries. The ground rules and assumptions for this cost estimation section represent overarching DMA specific cost assumptions as well as those used in the AASHTO LCC model.

The DMA cost estimation analysis only considers costs which are going to be incurred by the government. Therefore, only public sector costs are included in this analysis (e.g. privately owned light vehicles and truck equipment are not costed out). Furthermore, any user-experienced costs, such as buying a smart phone application or cellular data, are not accounted for in this model.

4.2.1 Cost Estimation Assumptions

Cost Breakdown Structure/Building Blocks:

> The AASHTO LCC model uses the "building blocks" identified from the CO-PILOT tool as the basis of the cost breakdown structure (CBS) used in the cost estimation model. These initial building blocks were further refined and completed after extensive research and analysis of the application architectures, the current design of each application, and discussions with several state and local transportation agency representatives. This CBS represents the physical goods, equipment, or training hours for personnel that are required to deploy an application. The DMA cost estimating model adapted the exact CBS as the basis for the analysis.

Cost Components:

> The AASHTO LCC team used detailed cost components for each of the building blocks to assess and identify the different cost elements required to enable the functionality of each application. The team performed extensive research beyond what was provided in the CO-PILOT tool to gather the key cost data. For example, "signalized intersections" are one of the building blocks required by multiple applications and it is broken down to lower-level cost components, such as roadside equipment and signal controllers, to clearly identify the sources of cost. The AASHTO LCC team documented all of their cost sources in their final report, which can be found in Appendix A.

Unit Costs:

> Unit costs used in the AASHTO LCC and subsequently in the DMA cost estimation model are dollar amounts associated with the purchase and installation of each cost component. These unit costs are either application-specific or they apply to multiple applications. The unit costs that are specific to an application are clearly specified in the CBS. The AASHTO LCC model includes average (i.e., most likely), minimum, and maximum unit costs for each of the cost components. The DMA team used the most likely value for each of the cost components as the default value in the model.

Operations and Maintenance (O&M) Costs:

> In general, the O&M costs represent any scheduled maintenance recurring costs spent during any operation maintenance activities or software updates. The AASHTO LCC model uses a 7% O&M cost for the capital costs of infrastructure-related hardware components, which is an industry standard percentage when better data is not available. This percentage is based on current industry best practices as determined by the AASHTO LCC team; the DMA cost estimation team also used this percentage in this model.

System Engineering Cost:

> The AASHTO LCC model has defined system engineering costs as any general design and planning activity related to development of requirements, reliability, logistic, and coordination of different teams over an application life cycle. A system engineering percentage of 10% has

been chosen as the default value applied to the capital costs of infrastructure-related hardware components based on the current industry standards. The DMA cost estimation model does not include this system engineering cost and any other outreach costs since it assumes the applications are fully designed and developed. Any software development and testing requirements for each application is captured under the “Software Development” CBS (cellular and DSRC) for each application.

Useful Life or Replacement Intervals:

Replacement intervals represent the estimated end of useful life of any hardware or software component, after which the item needs to be completely replaced or rehabbed. The DMA cost estimation model has adapted the useful life of each cost component from the AASHTO LCC model in order to remain consistent throughout the estimation model.

Volume Drivers:

Volume drivers are quantities and statistics collected at the national level from different sources such as the FHWA Office of Highway Policy Information, USDOT’s National Transportation Library, National Transit Database, FHWA Manual on Uniform Traffic Control Devices (MUTCD), Federal Motor Carrier Safety Administration (FMCSA), NHTSA National Driver Register (NDR), and other similar resources for the extrapolation analysis. The number of transit vehicles and their drivers, trucks and their drivers, freeway segments, signalized intersections, freeway on ramps, and freight terminals are all examples of volume drivers used in the DMA cost estimation analysis.

The volume driver for number of freeway segments cost element is based on the Impact Assessment of Dynamic Speed Harmonization with Queue Warning.[16] The INFLO impact assessment report defines a link as a segment of the roadway between two consecutive infrastructure based detector stations and assumes a length of 0.5 miles for its segments. The volume driver for number of freeway segments is calculated at the national level assuming a freeway segment is 0.5 miles.

The volume driver for number of signalized intersections in the United States was estimated based on FHWA MUTCD and a 2004 Institute of Transpiration (ITE) project, “Signal Timing Practices and Procedures: State of the Practice”, which included a survey of a large number of jurisdictions of all sizes, to estimate the total number of signalized intersections in the United States.[17]

Communication Components Required by Applications:

The different applications included in this DMA cost estimation analysis are currently in the prototype phase and not fully developed. Hence the communication networks, which will be

---

[16] “Impacts Assessment of Dynamic Speed Harmonization with Queue Warning Task 3 IA Report Version 3.1,” *U.S. Department of Transportation*, June 2015, http://ntl.bts.gov/lib/55000/55300/55307/Impact_Assesment_Report_Final_2015.pdf.

[17] “Manual on Uniform Traffic Control Devices. Frequently Asked Questions – Part 4 – Highway Traffic Signals,” *U.S. Department of Transportation*. http://mutcd.fhwa.dot.gov/knowledge/faqs/faq_part4.htm#tcsgq3.

used in the architecture of many of these applications, is not finalized yet. Therefore, the AASHTO LCC team included both DSRC and cellular based communication networks for the applicable cost elements. The DMA cost estimation team chose a combination of DSRC and cellular based communication cost components as a default for the applicable applications to consider the additional cost of these communication networks. Many of the IA and PD reports included both DSRC and cellular based communication networks in their prototype architecture and hence a similar combination was used in the DMA cost estimation model.

Application Deployment Rate:

The CV deployment during this period is according to the least aggressive safety application deployment curves as a percent of DSRC-equipped vehicles provided by NHTSA. Since the mobility applications will likely be deployed less aggressively than safety applications, the least aggressive safety application deployment curve as a percent of the on-board unit are applicable to the DMA program. NHTSA's safety application deployment rates were provided as a percent of DSRC-equipped vehicles. The application deployment and roadside units (RSU) deployment rates are assumed to be the same as the deployment rates provided by NHTSA. The costs are anticipated to occur in 2023 when the deployment rate begins and end by 2058 when this rate reaches 100%.

Discount Rate:

A discount rate was not used for the DMA cost estimation model. All costs are shown in 2012 dollars.

4.3 Data Sources

Cost data such as unit costs, one-time installation cost, and O&M costs were collected from the AASHTO LCC model as well as data on replacement intervals/useful life. This data is used to estimate the unit cost of individual cost elements for each application as discussed in the Methodology section below. A complete list of AASHTO LCC cost sources is documented in Appendix A.

The extrapolation factor, or volume drivers, are specific to each cost element in the CBS. Volume drivers are quantities and statistics collected at the national level from different sources, such as FHWA Office of Highway Policy Information, Federal Motor Carrier Safety Administration, Federal Transit Administration, the USDOT's National Transportation Library, and NHTSA National Driver Register (NDR). The total aggregated national level cost of each application is calculated by multiplying the unit costs of each element structure by its corresponding volume drivers on the national level, taking into account the NHTSA deployment rates.

4.4 Methodology

Cost estimation started by identifying the cost elements associated with the applications. These cost elements were then categorized, estimated, and associated with the applications. The detailed cost estimation methodology is described below.

4.4.1 Cost Breakdown Structure (CBS) and Cost Element Identification

The DMA cost estimation model is developed at the two digit CBS for each application which is consistent with the framework used in the AASHTO V2I LCC model and CO-PILOT tool. Based on the architecture and the necessary functionality of each application from the IA and PD reports, specific CBS elements were identified and cross-checked with the AASHTO LCC model and assigned to each application. The cross-checks included a review of the actual prototype architecture from the PD and IA reports as well as the CO-PILOT and the AASHTO LCC model. Table 11 provides a matrix summary of each application and their applicable CBS elements. For example, the cost elements applicable to the deployment of the INC-ZONE application (one of the applications under the R.E.S.C.U.M.E. bundle) includes the following elements:

- Transit vehicle
    - Transit retrofit kit/ on-board unit
    - Transit software package
    - App for mobile device (specific to INC-ZONE)
    - Mobile (cellular-based) carry-in device
    - Mobile device cellular data plan for 12 months
- Training hours for transit vehicle drivers
- Public safety vehicles
    - Public safety vehicle on-board unit
    - Public safety vehicle software package
    - App for mobile device (specific to INC-ZONE)
- Training hours for public safety vehicle drivers
- Trucks
    - Truck retrofit kit/ on-board unit
    - Truck software package
    - App for mobile device (specific to INC-ZONE)
    - Mobile (cellular-based) carry-in device
    - Mobile device cellular data plan for 12 months
- Training hours for truck drivers
- Freeway segments
    - Dynamic message signs
    - Roadside equipment (RSEs)
    - Roadside equipment planning and design
- Software development and testing for INC-ZONE application (considering both DSRC and cellular-based communication networks)

Table 11. Partial Cost Breakdown Structure for Multiple Applications

WBS	BUILDING BLOCKS	INC-ZONE	SPD-HARM	Q-WARN	FSP
1.1.	Drivers for Transit Vehicles	TRUE	TRUE	TRUE	
1.1.1.	Driver Training Hours: Transit Vehicles	TRUE	TRUE	TRUE	
1.3.	Freight Terminals				
1.3.1.	Roadside Equipment (RSEs)				
1.3.2.	RSE Planning & Design				
1.3.3.	Inductive Loop Detectors				
1.5.	Public Safety Vehicles	TRUE			
1.5.1.	Public safety vehicle OBU	TRUE			
1.5.2.	Public safety vehicle software package	TRUE			
1.5.3.	App for mobile device: INC-ZONE	TRUE			
1.6.	Signalized Intersections		TRUE	TRUE	TRUE
1.6.1.	Backhaul communications upgrade		TRUE	TRUE	TRUE
1.6.2.	Inductive Loop Detectors		TRUE	TRUE	
1.6.3.	RSE Planning & Design		TRUE	TRUE	TRUE
1.6.4.	Signal controllers		TRUE	TRUE	TRUE
1.6.5.	Roadside Equipment (RSEs)		TRUE	TRUE	TRUE
1.6.6.	Pucks (Sub-surface temperature sensors)			TRUE	
1.6.7.	Road Weather Information System (RWIS) pavement and atmos			TRUE	
1.6.8.	CCTV Camera			TRUE	
1.6.9.	Optical Detection System				
1.7.	Trucks	TRUE	TRUE	TRUE	TRUE
1.7.1.	Truck Retrofit kit / OBU	TRUE	TRUE	TRUE	TRUE
1.7.2.	Truck software package	TRUE	TRUE	TRUE	TRUE
1.7.3.	CACC Vehicle OBU Integration Modification				
1.7.4.	App for mobile device: INC-ZONE	TRUE			
1.7.5.	Mobile (cellular-based) carry-in device	TRUE	TRUE	TRUE	
1.7.6.	Mobile device cellular data plan for 12 months	TRUE	TRUE	TRUE	
1.7.7.	App for mobile device: SPD-HARM		TRUE		
1.7.8.	App for mobile device: Q-Warn			TRUE	
1.7.9.	App for mobile device: DO			TRUE	
1.8.	Drivers for Public Safety Vehicles	TRUE			
1.9.	Drivers for Trucks	TRUE	TRUE	TRUE	TRUE
1.9.1.	Driver Training Hours: Trucks	TRUE	TRUE	TRUE	TRUE
1.10.	Freeway Segments	TRUE	TRUE	TRUE	
1.10.1.	Dynamic Message Sign	TRUE			
1.10.2.	Backhaul communications upgrade		TRUE	TRUE	
1.10.3.	Inductive Loop Detectors		TRUE	TRUE	
1.10.4.	RSE Planning & Design	TRUE	TRUE	TRUE	
1.10.5.	Roadside Equipment (RSEs)	TRUE	TRUE	TRUE	
1.10.6.	Pucks (Sub-surface temperature sensors)			TRUE	
1.10.7.	Road Weather Information System (RWIS) pavement and atmos			TRUE	
1.10.8.	CCTV Camera			TRUE	
1.14.	Transit Vehicles	TRUE	TRUE	TRUE	
1.14.1.	Transit Retrofit kit / OBU	TRUE	TRUE	TRUE	
1.14.2.	Transit software package	TRUE	TRUE	TRUE	
1.14.3.	App for mobile device: INC-ZONE	TRUE			
1.14.4.	Mobile (cellular-based) carry-in device	TRUE	TRUE	TRUE	
1.14.5.	Mobile device cellular data plan for 12 months	TRUE	TRUE	TRUE	
1.14.6.	App for mobile device: SPD-HARM		TRUE		
1.14.7.	App for mobile device: Q-WARN			TRUE	
1.14.8.	App for mobile device: T-Connect				
1.14.9.	App for mobile device: T-Disp				
1.16.	Software Development	TRUE	TRUE	TRUE	TRUE
1.16.1.	Software Development & Testing: INC-ZONE (Cellular+DSRC)	TRUE			
1.16.2.	Software Development & Testing: RESP-STG (Cellular+DSRC)				
1.16.3.	Software Development & Testing: SPD-HARM (Cellular+DSRC)		TRUE		
1.16.4.	Software Development & Testing: Q-WARN (Cellular+DSRC)			TRUE	
1.16.5.	Software Development & Testing: CACC				
1.16.6.	Software Development & Testing: PED-SIG				
1.16.7.	Software Development & Testing: FSP				TRUE

Source: Booz Allen Hamilton, December 2015

4.4.2 Cost Types

Each of the cost elements within the CBS is categorized as one of the four broad cost types below:

- In-vehicle cost type
- Infrastructure cost type
- Software cost type
- Training cost type

This categorization allows the final costs to be broken down into the separate cost type buckets to allow for a more clear understanding and analysis of the cost components. The infrastructure costs are shown on a separate graph in Appendix C for each application due to the magnitude of this cost type. For the purpose of this analysis, it was assumed that no infrastructure is in place at the time of deployment (conservative approach).

4.4.3 Cost Components

Each CBS element is assigned an average unit price, a one-time installation cost, an O&M cost (percentage or a fixed cost), a useful life (i.e., replacement interval), and a quantity per building block. The average unit price for each cost element is obtained from the default average value used in the AASHTO LCC model. Many of the average unit prices used in the AASHTO LCC model are the same as the ones in the CO-PILOT tool. However, since the CO-PILOT tool was specifically designed for cost estimation related to the CV Pilot deployments, and not the actual full deployment of the applications, some of these costs have been updated based on extended research and external sources. All of the external sources used in the AASHTO cost model are included in Appendix A. The DMA cost estimation team used the default average unit prices from the AASHTO LCC model since it is the most comprehensive estimate currently available.

For example, the CBS 1.1.1. is named “Driver Training Hours: Transit Vehicles,” which represents the cost of training hours needed for each transit vehicle driver to get familiar with an application such as INC-ZONE. The average unit price for this CBS is $20.84 with a 0% O&M, no installation cost, a useful life of 1 year, and a quantity per building block of 2. This means each transit vehicle driver (who will be operating a vehicle with the INC-ZONE application installed) will need two hours (quantity per building block) of training every year (useful life). Hence:

Annual training unit cost for each driver = (average unit price * quantity per building block)

= $20.84 *2 = $41.68

This cost is categorized under the “training” cost type.

Another example is the transit retrofit kit / on-board unit installed on the transit vehicle itself. This CBS has an average unit price of $10,000, with a 7% O&M, $70.40 installation cost, 7 years of useful life, and a value of one for its quantity per building block field. This means that for each transit vehicle, there is an average unit price of $10,000 plus $70.40 installation cost on the first year. Hence:

Transit Retrofit Kit/OBU unit and installation cost for transit vehicle = (average unit price * quantity per building block+ installation cost)

= ($10,000 *1 + $70.40) = $10,070.40

This cost occurs every seven years when the useful life of the on-board unit ends. Additionally, an annual 7% O&M cost ($10,000 * 0.07 = $700) is allocated for the O&M costs of the on-board unit for any upgrades, wear and tear, or other maintenance expenses. This cost is categorized as “in-vehicle” cost type.

4.4.4 One-time Versus Recurring Costs

One-time costs or expenditures are those that are not recurring in nature. Examples include initial installation cost or initial off the shelf software development cost. Recurring costs represent the forecasted repeatedly-incurred costs, such as O&M costs or scheduled upgrades/development of software cost.

4.4.5 Volume Drivers

As previously mentioned, the extrapolation factors, or volume drivers, are specific to each cost element in the CBS. Volume drivers are quantities and statistics collected at the national level from different sources, such as FHWA Office of Highway Policy Information, the USDOT’s National Transportation Library, and other similar sources. In order to extrapolate unit costs to the national level, volume drivers such as number of trucks, transit vehicle, signalized intersections, and freeway segments were collected.

4.4.6 NHTSA CV Deployment Curves

The data elements collected in the previous step are used as the multipliers to extrapolate the unit prices to the national level costs based on the least aggressive NHTSA safety application deployment rates as a percent of DSRC-equipped vehicles. Three different safety application deployment rates as a percent of on-board unit deployments were provided by NHTSA. The team assumed that the lower values of application deployment percentages are applicable to the DMA program since the mobility applications will likely be deployed less aggressively than the safety applications. The upper, lower, and primary safety application deployment rates provided by NHTSA all converge by year 2030. These rates are provided for the entire nation and they do not consider any potential difference in urban and rural areas. Since this is the only source of data available to the cost estimation team, the volume drivers are collected at the national level and distributed based on the NHTSA application deployment rates. For example, the total number of government owned trucks are collected on the national level and used as a multiplier/volume driver without considering where these trucks operate on (arterial/highway) in the United States. This is noted as one of the limitations of the analysis later in this report.

Based on the selected NHTSA application deployment rates, the extrapolated national level costs for each cost element structure is forecasted for the years 2021 through 2060. Table 12 below summarizes the least aggressive safety application deployment rates provided by NHTSA as a percentage of the DRSC equipped vehicles.

Table 12. NHTSA Application Deployment Rates as a Percentage of the On-Road DSRC-Equipped Vehicles

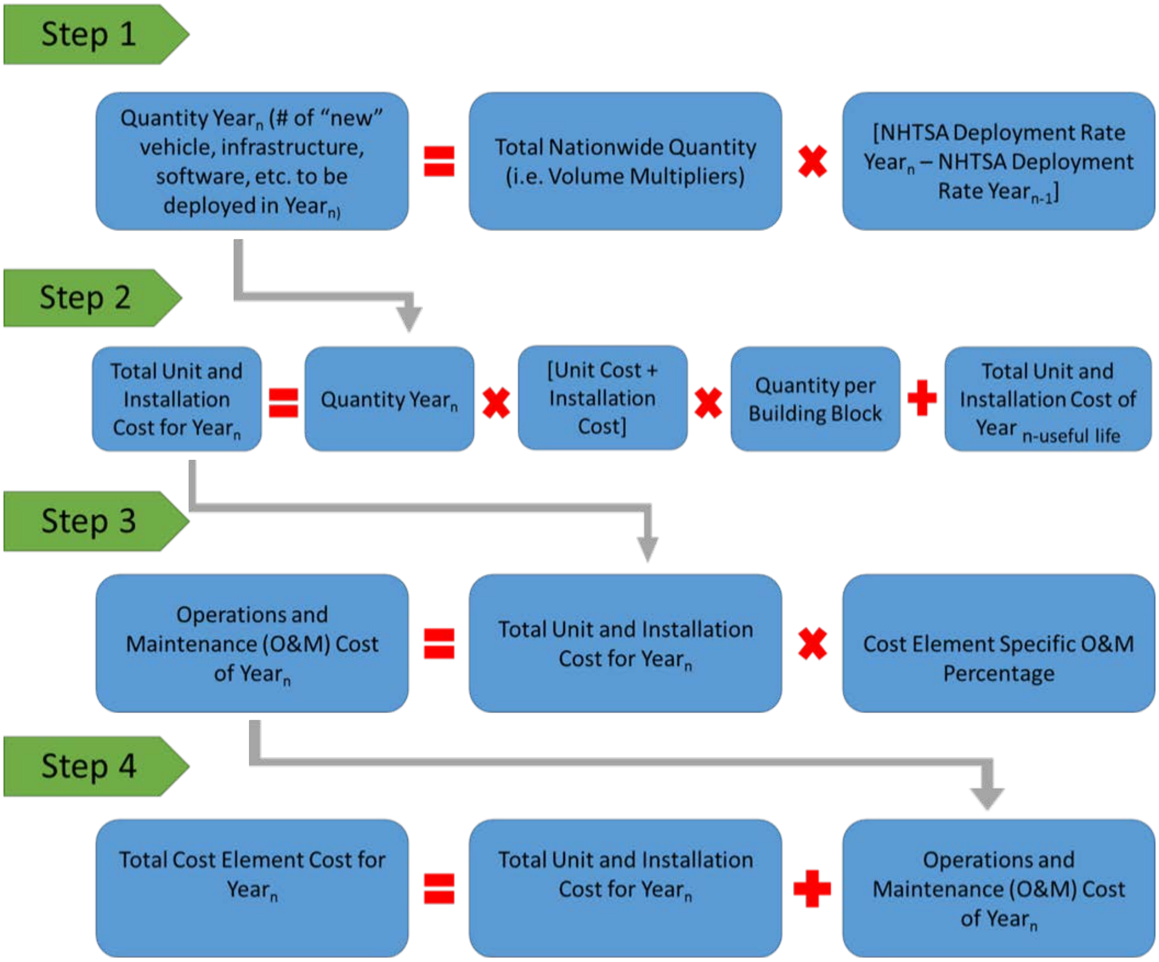
Year	On-Road Vehicles (%)	Year	On-Road Vehicles (%)	Year	On-Road Vehicles (%)	Year	On-Road Vehicles (%)
2021	0.0%	2031	60.8%	2041	92.4%	2051	98.9%
2022	0.0%	2032	65.5%	2042	93.6%	2052	99.2%
2023	0.6%	2033	69.8%	2043	94.7%	2053	99.4%
2024	1.7%	2034	73.9%	2044	95.5%	2054	99.6%
2025	5.2%	2035	77.6%	2045	96.2%	2055	99.7%
2026	10.1%	2036	81.0%	2046	96.8%	2056	99.8%
2027	19.3%	2037	84.0%	2047	97.3%	2057	99.9%
2028	30.6%	2038	86.7%	2048	97.8%	2058	100.0%
2029	44.4%	2039	88.9%	2049	98.2%	2059	100.0%
2030	55.8%	2040	90.8%	2050	98.6%	2060	100.0%

Source: Booz Allen Hamilton, June 2016

4.4.7 Overall Cost Estimation Methodology

The overall step-by-step national level cost estimation methodology is summarized in Figure 32 and discussed in detail below.

Figure 32. Overall DMA National Level Cost Estimation Methodology



Source: Booz Allen Hamilton, December 2015

4.4.7.1 Step 1

In order to estimate the annual deployment cost of each CBS for an application, the total number of "new" units (i.e., software, infrastructure, training hours, etc.) should be calculated for each year of the analysis period (2021-2060). As a clarification, a one-time software development and testing is applied to each application at the first year of analysis. After the first year, only a percentage for maintenance and upgrades is assigned to each application. As mentioned in the assumptions section, the volume driver quantities are mapped to the NHTSA deployment curves and applied to the appropriate years. Therefore, in order to calculate the number of "new" units deployed in year n, the appropriate total nationwide quantity (i.e., volume driver) for each cost element is multiplied by the incremental NHTSA deployment rate for year n.

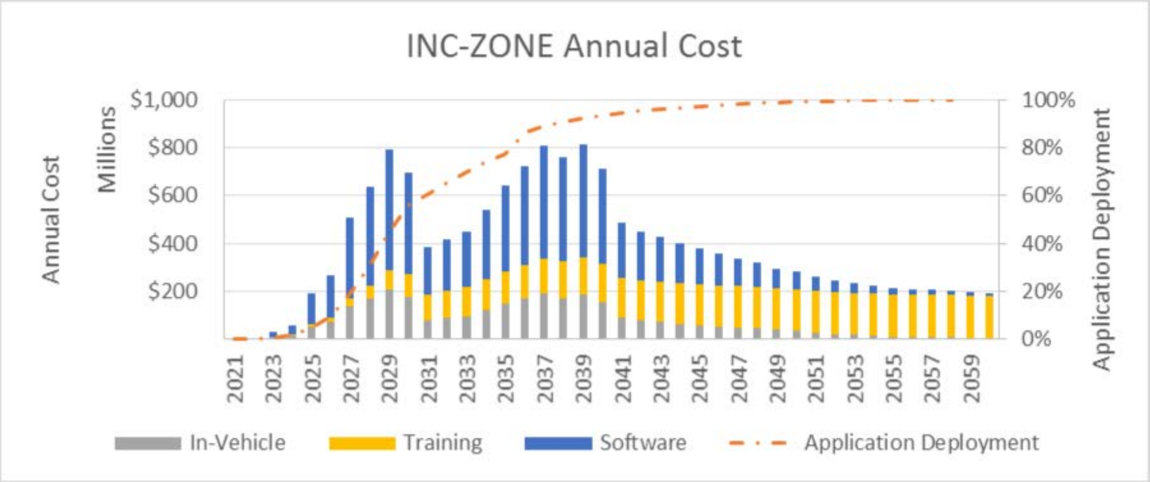
4.4.7.2 Step 2

Once the annual deployment quantity is calculated for each year of the analysis, the total unit and installation cost for each cost element is estimated at the national level. This value is obtained by multiplying the volume driver of year n by the purchasing and installing unit cost and then by the quantity per building block value for each CBS. In addition to the new deployed units each year, depending on the useful life of each cost element, an additional renewal cost may also be applied to each year. For example, assuming a cost element has 10 years of useful life, its total unit and installation cost in year 11 is the sum of the new deployed units in year 11 plus the total unit and installation cost of the year 1 (i.e. year n - useful life). The detailed formula is demonstrated under Step 2 in Figure 32 above.

The effect of the additional cost due to replacement intervals can be seen in the annual total deployment cost results charts for each application. For example, Figure 33 below shows the annual in-vehicle, training, and software costs of deploying INC-ZONE application at the national level from 2021 through 2060. Since multiple cost elements for this application have a 7 to 10 year useful life, a major peak in the cost is apparent in years 2031 through 2035. This jump is due to the cost of renewal units in addition to the purchase and installation of new units which are forecasted to be deployed in 2031-2035.

Even though the graph only shows this trend once, the methodology is applied to the entire period of analysis. This pattern is not apparent in the graph after the peak of 2031 due to the aggressive initial NHTSA application deployment rates. The dashed line on the graph below represents the NHTSA deployment curve and the rate at which units are forecasted to be deployed. The aggressive deployment rate during the first 10 years of the analysis results in the majority of vehicles being equipped with the applications early on. Therefore, after the first 10 years of analysis, the majority of the vehicles on the road have already been equipped with INC-ZONE and hence there are much lower in-vehicle and renewal costs incurred in the later years.

Figure 33. INC-ZONE Annual National Level Deployment Cost



Source: Booz Allen Hamilton, June 2016

4.4.7.3 Step 3

An annual O&M cost is applied to each cost element structure as either a percentage of the total unit and installation cost or a set value (depending on the data provided by the AASHTO LCC model).

4.4.7.4 Step 4

The total annual cost for each cost element is the sum of its total unit and installation cost plus its O&M cost.

Once the total annual cost of all cost elements are calculated, the CBS elements are aggregated based on their cost type category (in-vehicle, infrastructure, software, or training). Appropriate discounting rates are applied to the aggregated annual and cumulative cost results for each application and the results are summarized in bar graphs. The annual and cumulative deployment costs for each application is included in Application-Specific Cost Estimation Results section below.

4.4.8 Three Cost Results Scenarios

The deployment cost estimation results are summarized in the next section. All costs are shown in base year 2015 dollars. For each application, three set of annual and cumulative cost results are developed. The most likely and realistic scenario with cost sharing opportunities is included in the next section of this report. Appendix B contains reference charts that demonstrate conservative application-specific cost scenarios with no cost sharing opportunities. Appendix C describes total infrastructure costs for each application. Below is a description of each chart type and its purpose.

- **Application-Specific Costs Considering Some Cost Sharing Opportunities:** Many cost elements are shared among multiple applications. The charts presented for each application, summarize the overall in-vehicle, training, and software costs of each application, assuming some cost sharing opportunities among similar cost elements. The AASHTO LCC model includes a comprehensive list of V2I applications under the DMA program as well as other safety and environmental programs. The DMA cost estimation team used this list to map the number of applications which include the same cost elements and divided their *unit costs* among the applicable applications. For example, based on the list of V2I applications included in the AASHTO LCC model, five applications (INC-ZONE, RESP-STG, PREEMPT, Road Weather Information and Routing Support for Emergency Responders, and Advanced Automatic Crash Notification Relay) will require to have on-board units on public safety vehicles. In this case, the unit cost of “public safety vehicle on-board unit” is divided equally among the listed five applications. This scenario assumes that all of the applications will be deployed based on the NHTSA deployment curves throughout the nation. Even though this assumption does not exactly duplicate reality, these charts demonstrate some level of cost sharing opportunities among different applications and are less conservative than the previous charts.
- **Application-Specific Costs with No Cost Sharing:** These charts summarize the overall in-vehicle, training, and software costs of each application assuming that each application will require its own specific (and exclusive) equipment/software. Even though many applications will be able to utilize the same on-board equipment, off-the shelf software development, or potential combined training sessions, these charts demonstrate a conservative scenario with no cost sharing opportunities. These charts are intended to provide an insight into the national level implementation costs of individual applications in the absence of any other application and can be found in Appendix B.

- **Infrastructure Costs:** These charts include the overall infrastructure cost necessary for deployment of each application. This type of chart is intended to demonstrate the “worst case scenario” from a costing perspective in which the entire infrastructure has to be put in place before the deployment of the application in the entire nation. Even though this scenario is not realistic, it helps provide a rough order of magnitude cost estimation for the decision makers and agencies. In reality, much of the current CV infrastructure will be utilized and different applications will be able to leverage the same infrastructure components and communication networks. This scenario is conservative since it assumes all the corridors and regions in the United States will be equipped with the necessary infrastructure to support all of the DMA applications discussed in this analysis. The infrastructure costs for each application is included in Appendix C.

4.5 Application-Specific Cost Estimation Results

4.5.1 Intelligent Network Flow Optimization (INFLO)

SPD-HARM and Q-WARN were the two applications studied under this bundle. As mentioned earlier in this report, these freeway applications were bundled up in the IA analysis since they will be likely deployed together for optimal impacts. However, the annual extrapolated costs of each of these applications are shown separately in this section. Table 13 below summarizes the cost breakdown structure and cost types of the cost elements that apply to either SPD-HARM and/or Q-WARN applications based on the AASHTO LCC model. All assumptions used in the AASHTO model have been applied to this cost estimation and the cost elements included in the table below are in line with AASHTO LCC V2I model and CO-PILOT tool. No additional assumptions were made regarding the cost element structure by the team.

The estimated infrastructure cost components are based on the *System Design Document for the INFLO Prototype*[18] and *Technical Report on Prototype Intelligent Network Flow Optimization (INFLO) Dynamic Speed Harmonization and Queue Warning.*[19] Some of the infrastructure and in-vehicle cost components are predicted to be lower than the estimated values reported in the Cost Estimation section of this report due to potential improvements in application development and infrastructure usage. For example, based on the INFLO IA report, it is assumed that speed recommendations are needed at every freeway segment (every 0.5 miles). It is important to note that the 0.5 miles gantry spacing reported in the INFLO IA Report is influenced by the gantry spacing which has been used by Washington Department of Transportation on the Seattle Testbed for a small-scale INFLO demonstration. Consequently, this is not a standard value. Gantry spacing is a user-definable parameter in the micro simulation model used for this IA.

The data needs to be disseminated at the same resolution requiring road side equipment and dynamic message signs at every 0.5 miles of the highways to communicate to in-vehicle devices and provide speed recommendations. The assumptions made for each application in this National Level Cost Estimation Model is based on the reported IA. Since the INFLO IA team did not use cellular

---

[18] “System Design Document for the INFLO Prototype,” *U.S. Department of Transportation*, March 2014, http://ntl.bts.gov/lib/54000/54800/54846/INFLO-System-Design-FINAL-508-compliant_FHWA-JPO-14-169.pdf.

[19] “Technical Report on Prototype Intelligent Network Flow Optimization (INFLO) Dynamic Speed Harmonization and Queue Warning,” *U.S. Department of Transportation*, June 2015, http://ntl.bts.gov/lib/55000/55300/55304/100030614-601_Technical_Report_on_Prototype_Intelligent_Network_Flow_Optimization_Final_.pdf.

communication for their prototypes, this analysis has excluded the option of using cellular communications in its cost estimations. However, using cellular communication for the actual deployment of these applications could result in a lower overall cost compared to the values currently reported.

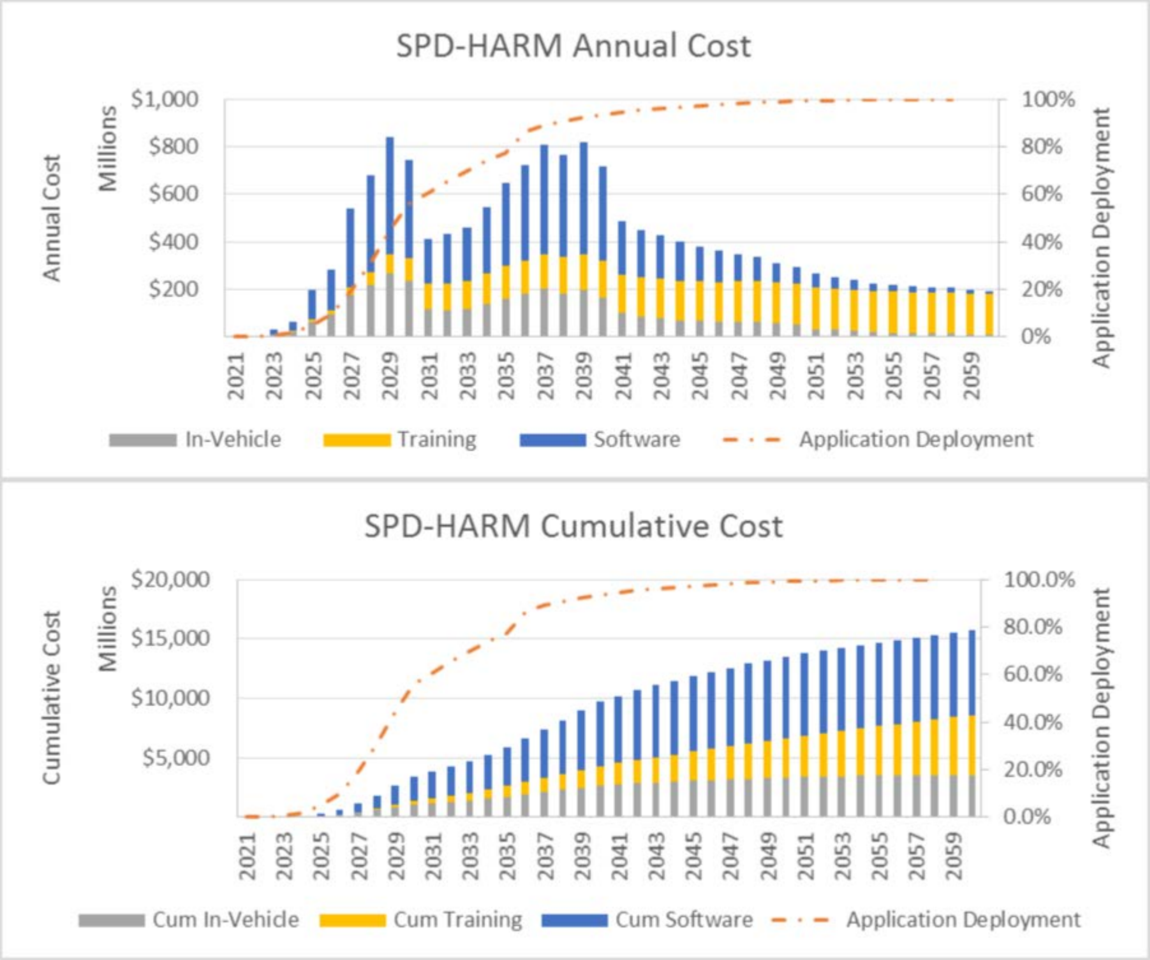
Table 13. SPD-HARM and Q-WARN Cost Breakdown Structure

WBS	BUILDING BLOCKS	Cost Type	SPD-HARM	Q-WARN
1.1.	*Drivers for Transit Vehicles*		*TRUE*	*TRUE*
1.1.1.	*Driver Training Hours: Transit Vehicles*	*Training*	*TRUE*	*TRUE*
1.6.	*Signalized Intersections*		*TRUE*	*TRUE*
1.6.1.	*Backhaul communications upgrade*	*Infrastructure*	*TRUE*	*TRUE*
1.6.2.	*Inductive Loop Detectors*	*Infrastructure*	*TRUE*	*TRUE*
1.6.3.	*RSE Planning & Design*	*In-Vehicle*	*TRUE*	*TRUE*
1.6.4.	*Signal controllers*	*Infrastructure*	*TRUE*	*TRUE*
1.6.5.	*Roadside Equipment (RSEs)*	*Infrastructure*	*TRUE*	*TRUE*
1.6.6.	*Pucks (Sub-surface temperature sensors)*	*Infrastructure*		*TRUE*
1.6.7.	*Road Weather Information System (RWIS) pavement and atmos*	*Infrastructure*		*TRUE*
1.6.8.	*CCTV Camera*	*Infrastructure*		*TRUE*
1.7.	*Trucks*		*TRUE*	*TRUE*
1.7.1.	*Truck Retrofit kit / OBU*	*In-Vehicle*	*TRUE*	*TRUE*
1.7.2.	*Truck software package*	*Software*	*TRUE*	*TRUE*
1.7.5.	*Mobile (cellular-based) carry-in device*	*In-Vehicle*	*TRUE*	*TRUE*
1.7.6.	*Mobile device cellular data plan for 12 months*	*In-Vehicle*	*TRUE*	*TRUE*
1.7.7.	*App for mobile device: SPD-HARM*	*In-Vehicle*	*TRUE*	
1.7.8.	*App for mobile device: Q-Warn*	*In-Vehicle*		*TRUE*
1.9.	*Drivers for Trucks*		*TRUE*	*TRUE*
1.9.1.	*Driver Training Hours: Trucks*	*Training*	*TRUE*	*TRUE*
1.10.	*Freeway Segments*		*TRUE*	*TRUE*
1.10.2.	*Backhaul communications upgrade*	*Infrastructure*	*TRUE*	*TRUE*
1.10.3.	*Inductive Loop Detectors*	*Infrastructure*	*TRUE*	*TRUE*
1.10.4.	*RSE Planning & Design*	*In-Vehicle*	*TRUE*	*TRUE*
1.10.5.	*Roadside Equipment (RSEs)*	*Infrastructure*	*TRUE*	*TRUE*
1.10.6.	*Pucks (Sub-surface temperature sensors)*	*Infrastructure*		*TRUE*
1.10.7.	*Road Weather Information System (RWIS) pavement and atmos*	*Infrastructure*		*TRUE*
1.10.8.	*CCTV Camera*	*Infrastructure*		*TRUE*
1.14.	*Transit Vehicles*		*TRUE*	*TRUE*
1.14.1.	*Transit Retrofit kit / OBU*	*In-Vehicle*	*TRUE*	*TRUE*
1.14.2.	*Transit software package*	*Software*	*TRUE*	*TRUE*
1.14.4.	*Mobile (cellular-based) carry-in device*	*In-Vehicle*	*TRUE*	*TRUE*
1.14.5.	*Mobile device cellular data plan for 12 months*	*In-Vehicle*	*TRUE*	*TRUE*
1.14.6.	*App for mobile device: SPD-HARM*	*In-Vehicle*	*TRUE*	
1.14.7.	*App for mobile device: Q-WARN*	*In-Vehicle*		*TRUE*
1.16.	*Software Development*		*TRUE*	*TRUE*
1.16.3.	*Software Development & Testing: SPD-HARM (Cellular+DSRC)*	*Software*	*TRUE*	
1.16.4.	*Software Development & Testing: Q-WARN (Cellular+DSRC)*	*Software*		*TRUE*

Source: Booz Allen Hamilton, December 2015

SPD-HARM: Below are the estimated total annual and cumulative cost results of deploying the SPD-HARM application on the national level with cost sharing opportunities.

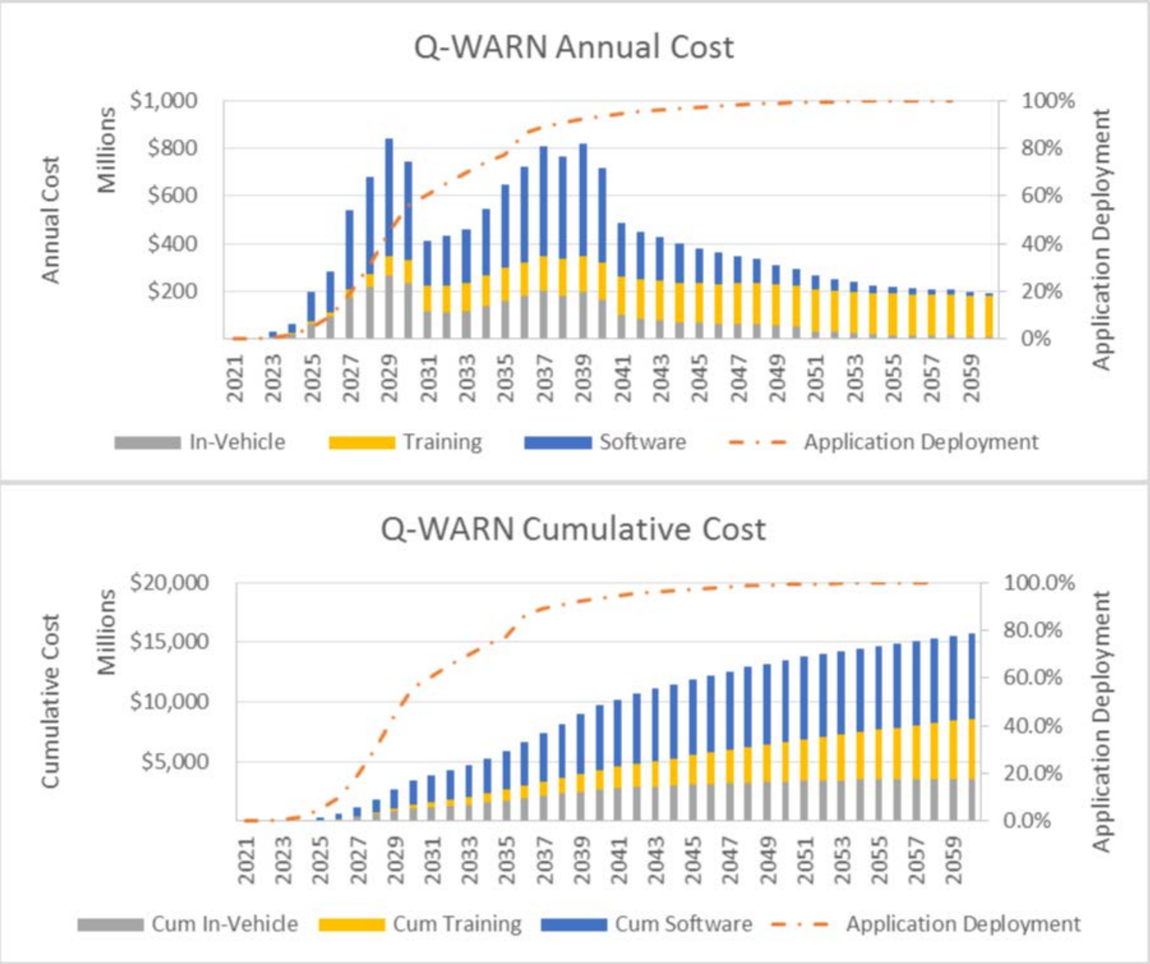
Figure 34. SPD-HARM Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

Queue Warning (Q-WARN): Below are the estimated annual and total cumulative costs of deploying Q-WARN application on the national level considering cost sharing opportunities.

Figure 35. Q-WARN Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

4.5.2 Multi-Modal Intelligent Traffic Signal Systems (MMITSS)

The MMITSS IA analysis was carried out for the I-SIG, TSP, and FSP applications. These applications are designed to improve the signal operations on arterials. Table 14 below summarizes the cost breakdown structure and cost types of the cost elements, which apply to either the I-SIG, TSP, and/or FSP applications based on the AASHTO LCC model. All assumptions used in the AASHTO model have been applied to this cost estimation and the cost elements included in the table below are in line with AASHTO LCC V2I model and CO-PILOT tool. No additional assumptions were made regarding the cost element structure by the team.

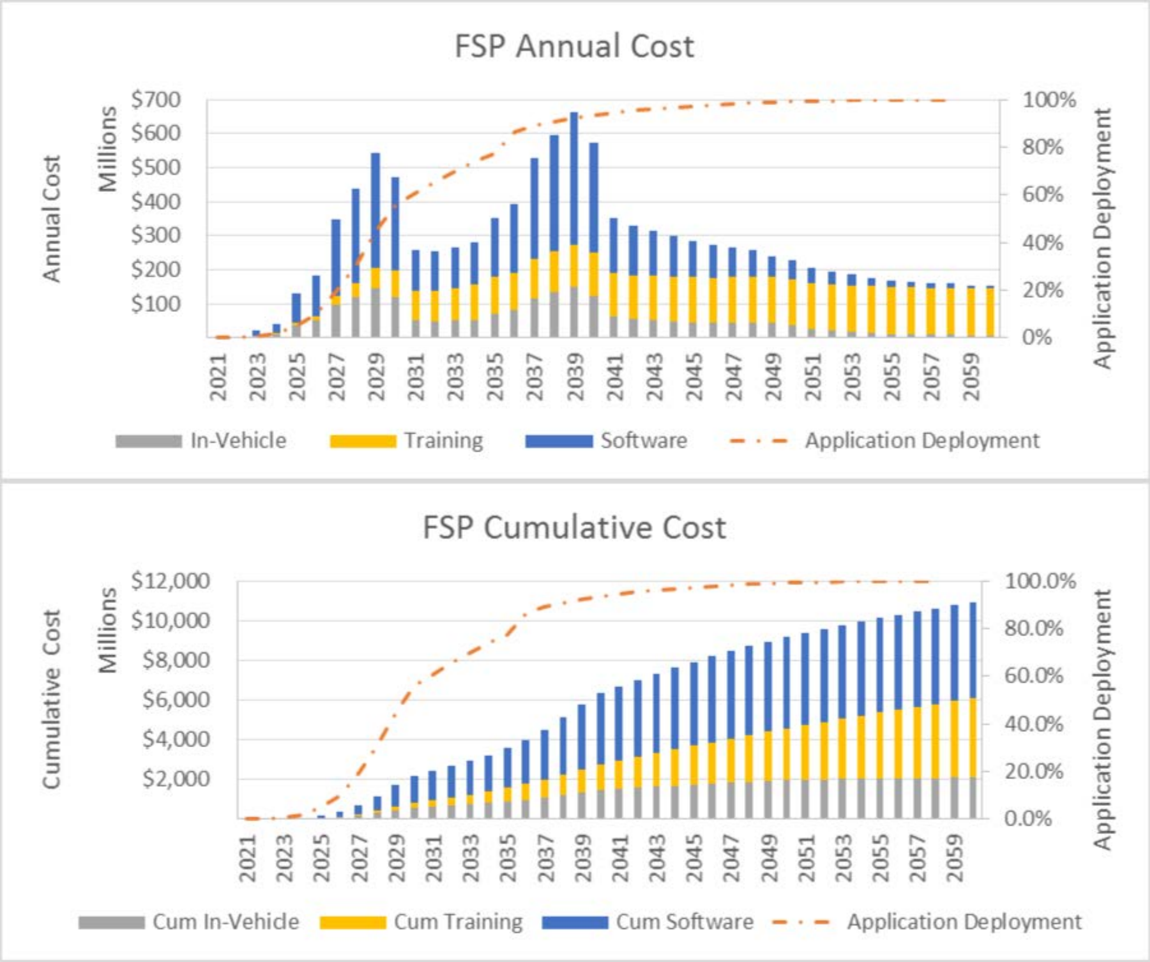
Table 14. FSP, TSP, and I-SIG Cost Breakdown Structure

WBS	BUILDING BLOCKS	Cost Type	FSP	TSP	I-SIG
1.1.	Drivers for Transit Vehicles			TRUE	TRUE
1.1.1.	Driver Training Hours: Transit Vehicles	Training		TRUE	TRUE
1.5.	Public Safety Vehicles				TRUE
1.5.1.	Public safety vehicle OBU	In-Vehicle			TRUE
1.5.2.	Public safety vehicle software package	Software			TRUE
1.6.	Signalized Intersections		TRUE	TRUE	TRUE
1.6.1.	Backhaul communications upgrade	Infrastructure	TRUE	TRUE	TRUE
1.6.2.	Inductive Loop Detectors	Infrastructure			TRUE
1.6.3.	RSE Planning & Design	In-Vehicle	TRUE	TRUE	TRUE
1.6.4.	Signal controllers	Infrastructure	TRUE	TRUE	TRUE
1.6.5.	Roadside Equipment (RSEs)	Infrastructure	TRUE	TRUE	TRUE
1.6.6.	Pucks (Sub-surface temperature sensors)	Infrastructure			TRUE
1.6.7.	Road Weather Information System (RWIS) pavement and atmos	Infrastructure			TRUE
1.6.9.	Optical Detection System	In-Vehicle			TRUE
1.7.	Trucks		TRUE		TRUE
1.7.1.	Truck Retrofit kit / OBU	In-Vehicle	TRUE		TRUE
1.7.2.	Truck software package	Software	TRUE		TRUE
1.8.	Drivers for Public Safety Vehicles	Training			TRUE
1.9.	Drivers for Trucks		TRUE		TRUE
1.9.1.	Driver Training Hours: Trucks	Training	TRUE		TRUE
1.14.	Transit Vehicles			TRUE	TRUE
1.14.1.	Transit Retrofit kit / OBU	In-Vehicle		TRUE	TRUE
1.14.2.	Transit software package	Software		TRUE	TRUE
1.16.	Software Development		TRUE	TRUE	TRUE
1.16.7.	Software Development & Testing: FSP	Software	TRUE		
1.16.8.	Software Development & Testing: TSP	Software		TRUE	
1.16.10.	Software Development & Testing: I-SIG	Software			TRUE

Source: Booz Allen Hamilton, December 2015

Freight Signal Priority (FSP): Below are the estimated annual and total cumulative cost results of deploying the FSP application on the national level considering cost sharing opportunities.

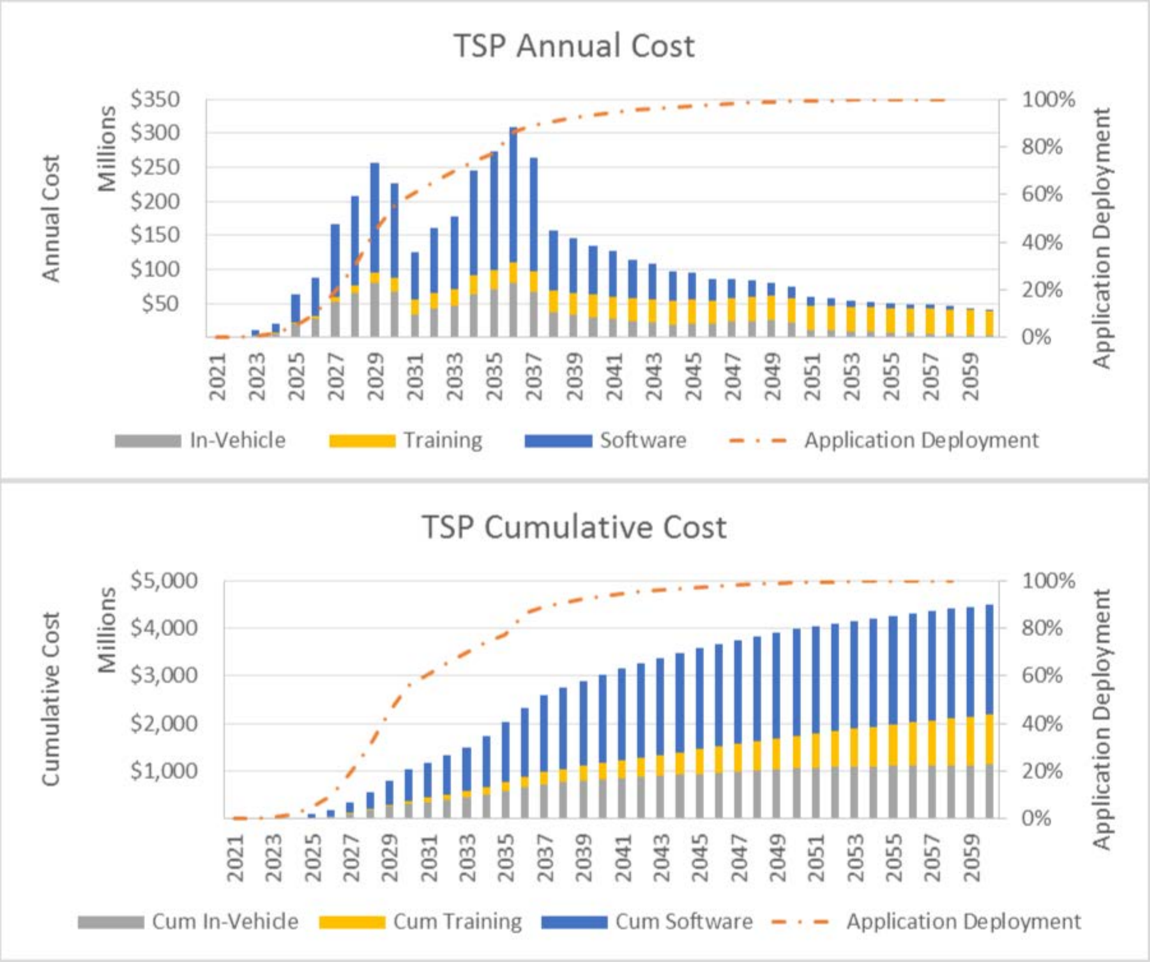
Figure 36. FSP Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

Transit Signal Priority (TSP): Below are the estimated annual and total cumulative cost results of deploying the TSP application on the national level considering cost sharing opportunities.

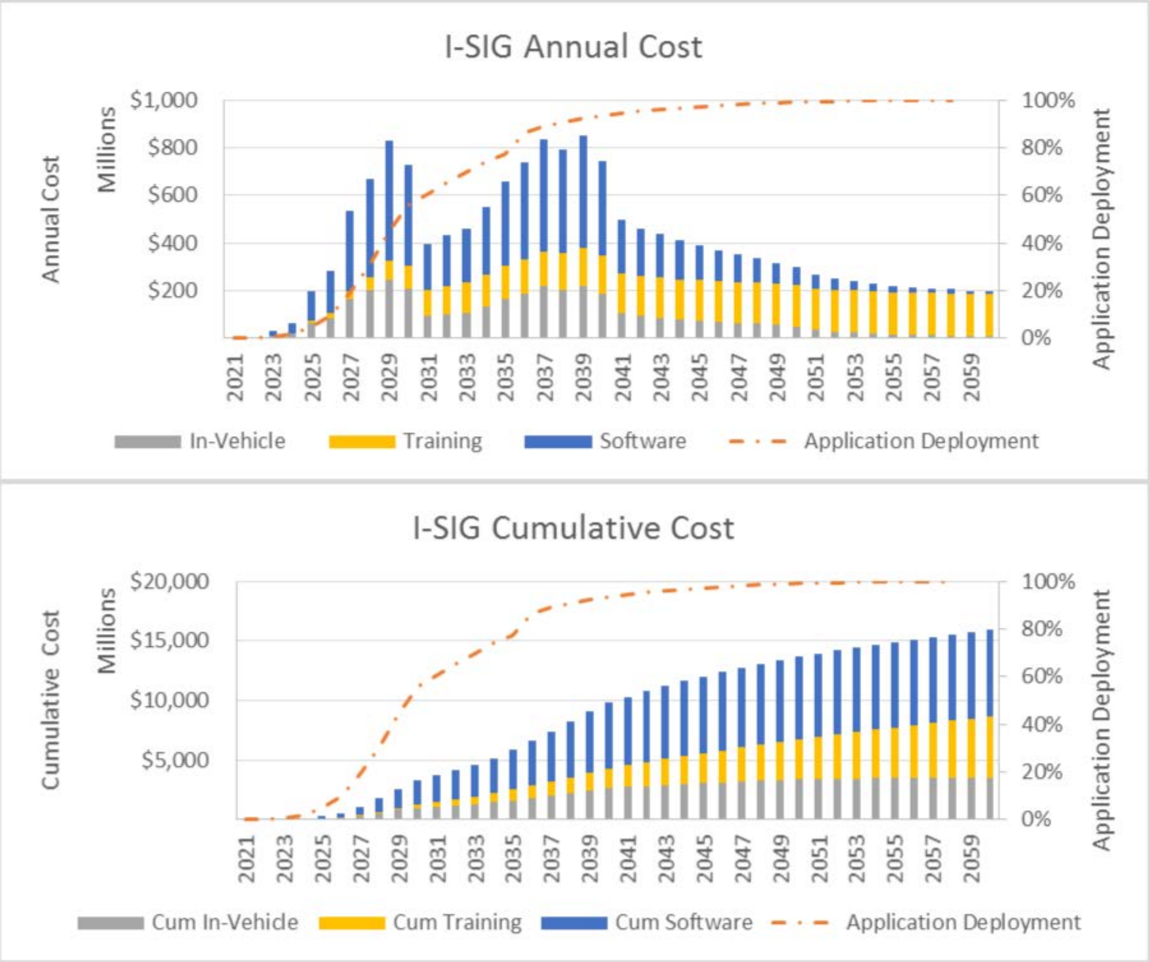
Figure 37. TSP Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

Intelligent Traffic Signal System (I-SIG): Below are the estimated annual and total cumulative deployment costs of deploying I-SIG on the national level considering cost sharing opportunities.

Figure 38. I-SIG Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

4.5.3 Response, Emergency Staging and Communications, Uniform Management, and Evaluation (R.E.S.C.U.M.E.)

The R.E.S.C.U.M.E. IA study estimated regional mobility impacts for the INC-ZONE application. Table 15 below summarizes the cost breakdown structure and cost types of the cost elements for the INC-ZONE application based on the AASHTO LCC model. All assumptions used in the AASHTO model have been applied to this cost estimation and the cost elements included in the table below are in line with AASHTO LCC V2I model and CO-PILOT tool. No additional assumptions were made regarding the cost element structure by the team.

Table 15. INC-ZONE Cost Breakdown Structure

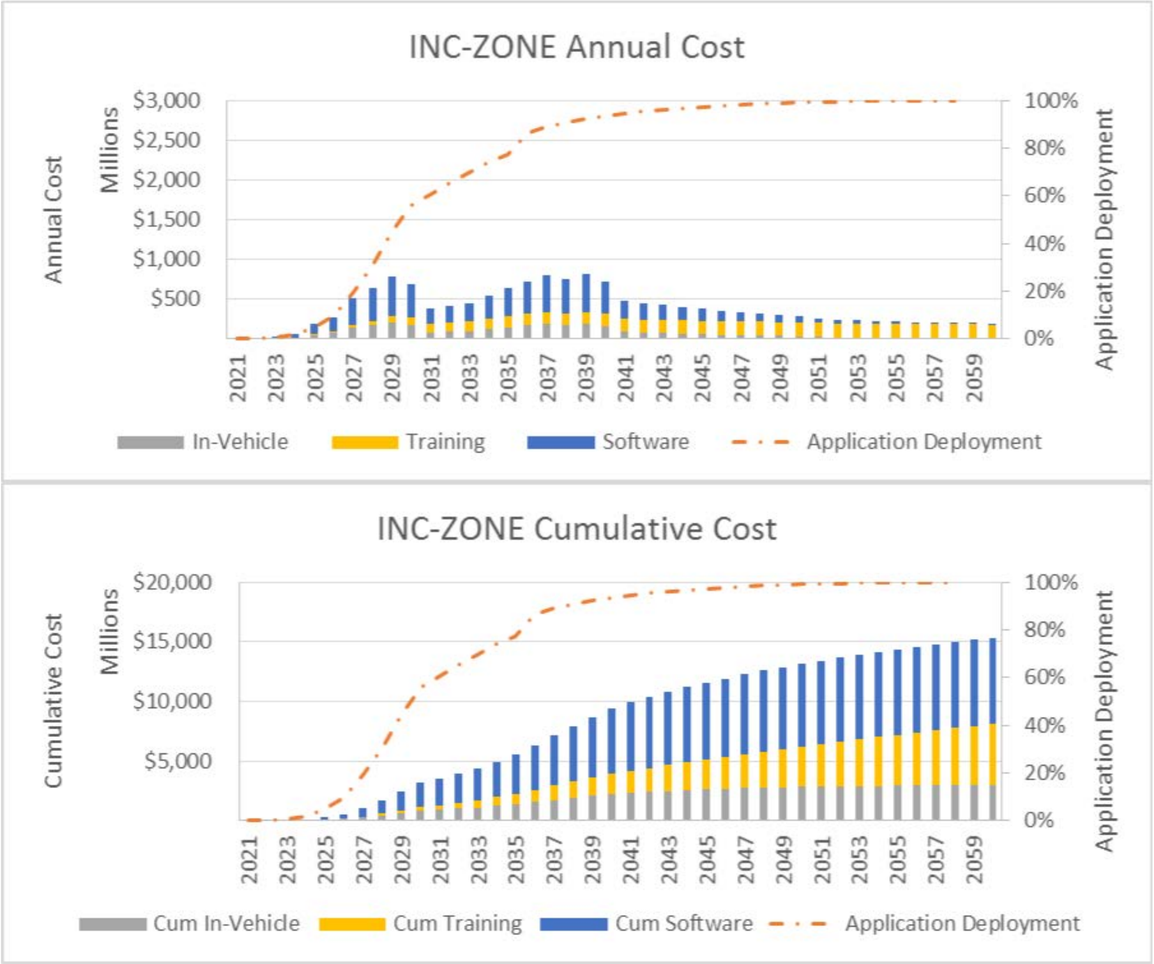
WBS	BUILDING BLOCKS	Cost Type	INC-ZONE
1.1.	Drivers for Transit Vehicles		TRUE
1.1.1.	Driver Training Hours: Transit Vehicles	Training	TRUE
1.5.	Public Safety Vehicles		TRUE
1.5.1.	Public safety vehicle OBU	In-Vehicle	TRUE
1.5.2.	Public safety vehicle software package	Software	TRUE
1.5.3.	App for mobile device: INC-ZONE	In-Vehicle	TRUE
1.7.	Trucks		TRUE
1.7.1.	Truck Retrofit kit / OBU	In-Vehicle	TRUE
1.7.2.	Truck software package	Software	TRUE
1.7.4.	App for mobile device: INC-ZONE	In-Vehicle	TRUE
1.7.5.	Mobile (cellular-based) carry-in device	In-Vehicle	TRUE
1.7.6.	Mobile device cellular data plan for 12 months	In-Vehicle	TRUE
1.8.	Drivers for Public Safety Vehicles	Training	TRUE
1.9.	Drivers for Trucks		TRUE
1.9.1.	Driver Training Hours: Trucks	Training	TRUE
1.10.	Freeway Segments		TRUE
1.10.1.	Dynamic Message Sign	Infrastructure	TRUE
1.10.4.	RSE Planning & Design	In-Vehicle	TRUE
1.10.5.	Roadside Equipment (RSEs)	Infrastructure	TRUE
1.14.	Transit Vehicles		TRUE
1.14.1.	Transit Retrofit kit / OBU	In-Vehicle	TRUE
1.14.2.	Transit software package	Software	TRUE
1.14.3.	App for mobile device: INC-ZONE	In-Vehicle	TRUE
1.14.4.	Mobile (cellular-based) carry-in device	In-Vehicle	TRUE
1.14.5.	Mobile device cellular data plan for 12 months	In-Vehicle	TRUE
1.16.	Software Development		TRUE
1.16.1.	Software Development & Testing: INC-ZONE (Cellular+DSRC)	Software	TRUE

Source: Booz Allen Hamilton, December 2015

4.5.3.1 Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)

Below are the estimated annual and total cumulative costs of deploying the INC-ZONE application on the national level while considering cost sharing opportunities.

Figure 39. INC-ZONE Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

4.5.4 Enable Advanced Traveler Information Systems (EnableATIS)

The AMS Testbed study captured the mobility impacts for the EnableATIS application. As explained in the Application Descriptions section under the Introduction chapter of this report, the EnableATIS bundle includes four applications: ATIS, S-PARK, T-MAP, and WX-INFO. The AMS Testbed Phoenix network study focused only on the ATIS application and hence the associated costs of ATIS application was considered in this report. The ATIS application integrates travel-time reliability in a multimodal environment by integrating data from different sources and disseminating it to users via different media. The EnableATIS application on the Phoenix testbed essentially provided a time-dependent shortest path from origin to destination for travelers (pre-trip planning) or from the current location to destination (en-route rerouting).

According to CO-PILOT tool, the cost components for ATIS application are all related to multimodal travelers. The CES for ATIS in the CO-PILOT tool are:

- Multimodal traveler training hours
- Mobile device cellular data plan
- Mobile (cellular-based) carry-in device
- App for mobile device

All of the cost elements listed above will be incurred by the individual travelers and not the government. This report has only focused on the costs which will be incurred by the government (i.e., infrastructure owners and operators) and the only applicable cost for this analysis is a one-time software development and testing cost of $400,000 and a 7% recurring O&M and software upgrade cost.

4.5.5 Freight Advanced Traveler Information System (FRATIS)

The FRATIS bundle includes Freight Specific Dynamic Travel Planning and Performance (FSDTPP) and Drayage Optimization (DR-OPT) applications. The FSDTPP application includes all of the traveler information, dynamic routing, and performance monitoring elements that freight truck users need in one application and leverage existing data in the public domain, as well as emerging private sector applications. The DR-OPT application combines container load matching and freight information exchange systems to fully optimize drayage operations.

The number of trucks and their drivers are two of the volume multipliers used to estimate the cost of these two bundles. Since the cost estimation section of this report has only considered costs that will occur to the government, only the number of government owned trucks have been used as volume multipliers.

Table 16 below summarizes the cost breakdown structure and cost types of the cost elements which apply to either the FSDTPP and/or DR-OPT applications based on the AASHTO LCC model. All assumptions used in the AASHTO model have been applied to this cost estimation and the cost elements included in the table below are in line with AASHTO LCC V2I model and CO-PILOT tool. No additional assumptions were made regarding the cost element structure by the team.

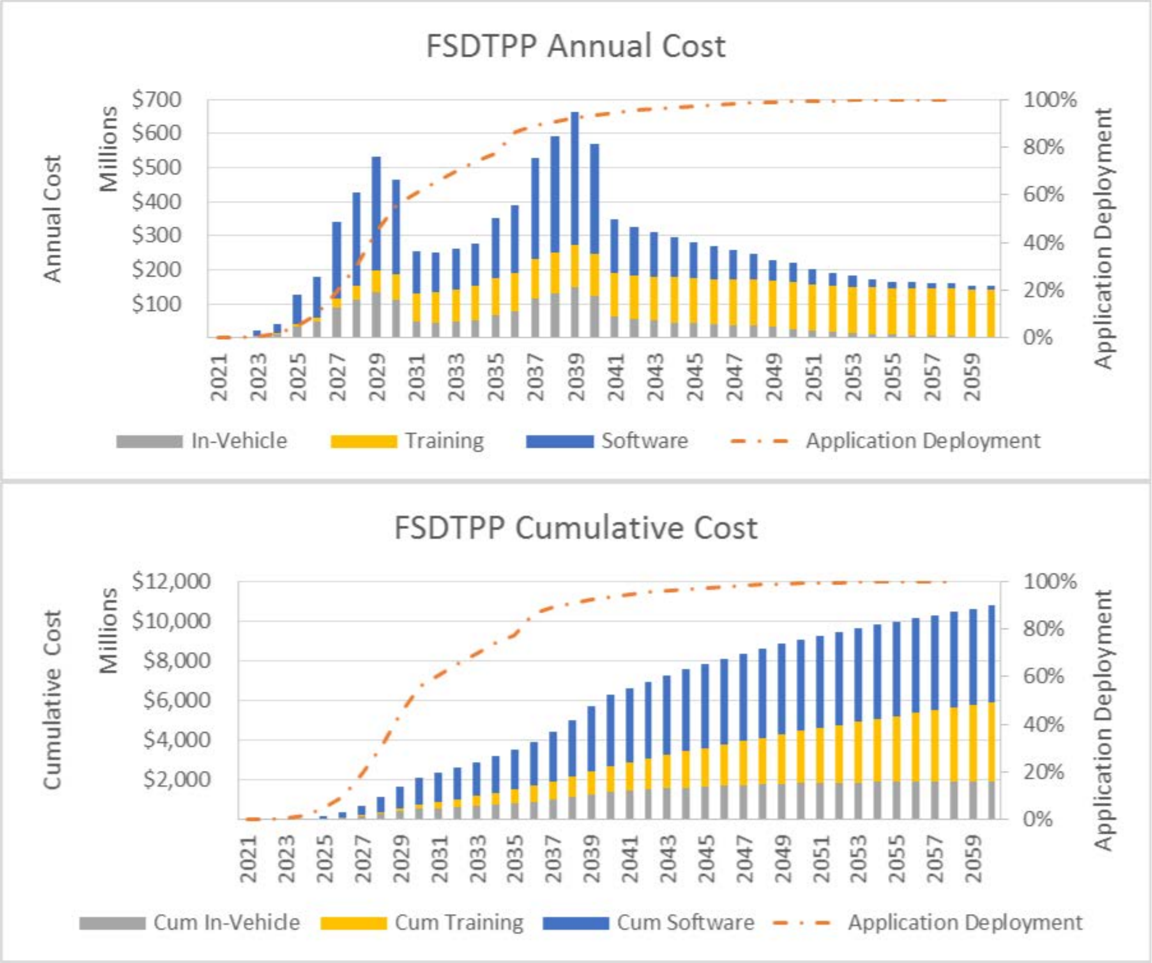
Table 16. FRATIS Cost Breakdown Structure

WBS	BUILDING BLOCKS	Cost Type	FSDTPP	DR-OPT
1.3.	Freight Terminals			TRUE
1.3.1.	Roadside Equipment (RSEs)	Infrastructure		TRUE
1.3.2.	RSE Planning & Design	Infrastructure		TRUE
1.3.3.	Inductive Loop Detectors	Infrastructure		TRUE
1.7.	Trucks		TRUE	TRUE
1.7.1.	Truck Retrofit kit / OBU	In-Vehicle	TRUE	TRUE
1.7.2.	Truck software package	Software	TRUE	TRUE
1.7.5.	Mobile (cellular-based) carry-in device	In-Vehicle		TRUE
1.7.6.	Mobile device cellular data plan for 12 months	In-Vehicle		TRUE
1.7.9.	App for mobile device: DR-OPT	In-Vehicle		TRUE
1.9.	Drivers for Trucks		TRUE	TRUE
1.9.1.	Driver Training Hours: Trucks	Training	TRUE	TRUE
1.10.	Freeway Segments		TRUE	
1.10.2.	Backhaul communications upgrade	Infrastructure	TRUE	
1.10.3.	Inductive Loop Detectors	Infrastructure	TRUE	
1.10.4.	RSE Planning & Design	In-Vehicle	TRUE	
1.10.5.	Roadside Equipment (RSEs)	Infrastructure	TRUE	
1.16.13.	Software Development & Testing: FSDTPP	Software	TRUE	
1.16.14.	Software Development & Testing: DR-OPT	Software		TRUE

Source: Booz Allen Hamilton, June 2016

Freight Specific Dynamic Travel Planning and Performance (FSDTPP): Below are the estimated annual and total cumulative cost results of deploying the FSDTPP application on the national level considering cost sharing opportunities.

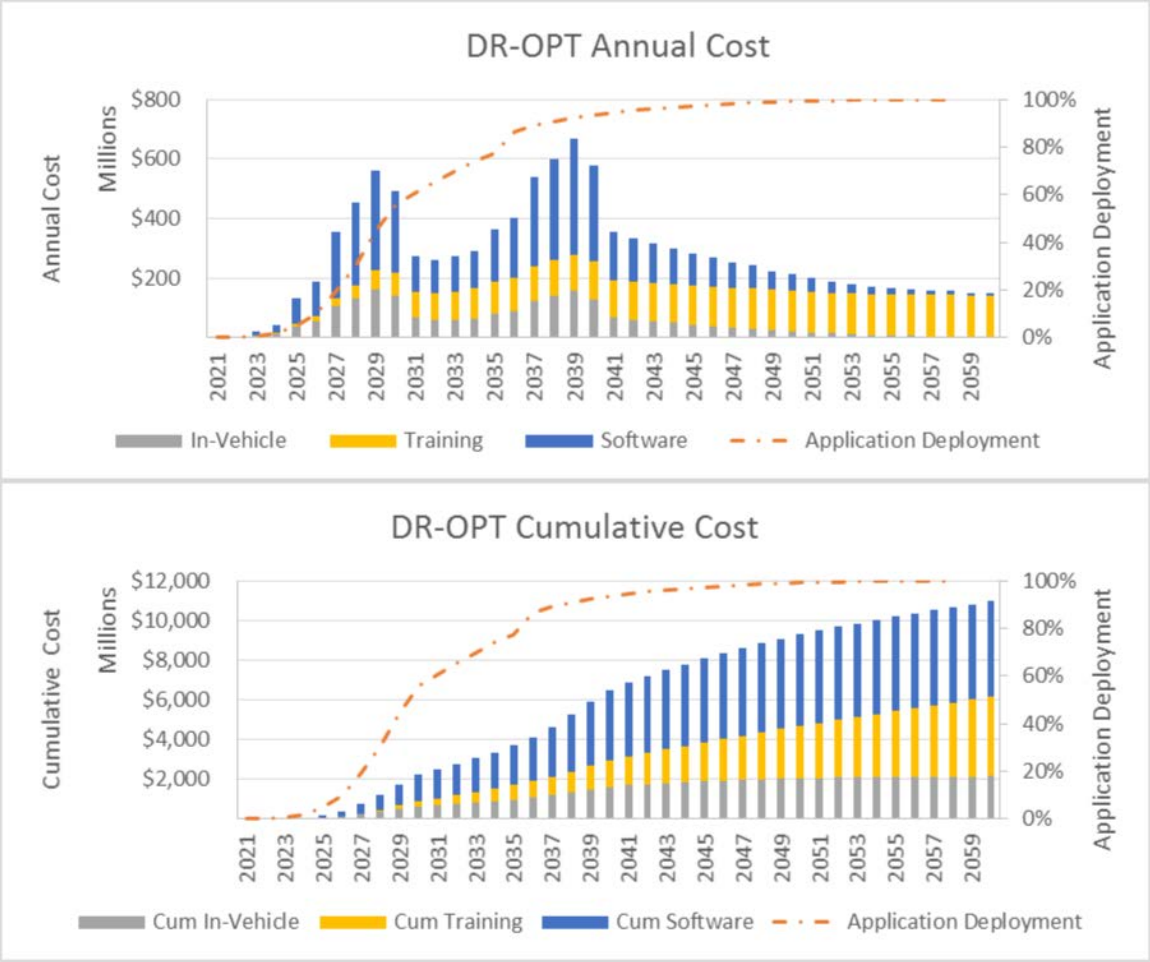
Figure 40. FSDTPP Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

Drayage Optimization (DR-OPT): Below are the estimated annual and total cumulative cost results of deploying the DR-OPT application on the national level considering cost sharing opportunities.

Figure 41. DR-OPT Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

4.5.6 Integrated Dynamic Transit Operations (IDTO)

The IDTO bundle includes T-CONNECT and T-DISP applications. The T-CONNECT application aims to improve transfers between both transit and non-transit modes as well as coordinating between different agencies to enhance ride satisfaction and reduce trip time for multimodal travelers. The T-DISP application aims to advance demand-responsive transportation services through the use of existing technology systems and the expansion of transportation options. It seeks to match travelers' requests for trips with available transportation providers' services.

Neither CO-PILOT tool nor AASHTO LCC's CES include a Transit Software Package cost for these two applications. Only a one time software development and testing cost was included in these two tools. However, for the purposes of this cost estimation study, the team assumed a Transit Software Package cost for all the transit vehicles similar to what had been used for other applications.

Table 17 summarizes the cost breakdown structure and cost types of the cost elements that apply to either the T-CONNECT and/or T-DISP applications based on the AASHTO LCC model and additional assumptions regarding software packages.

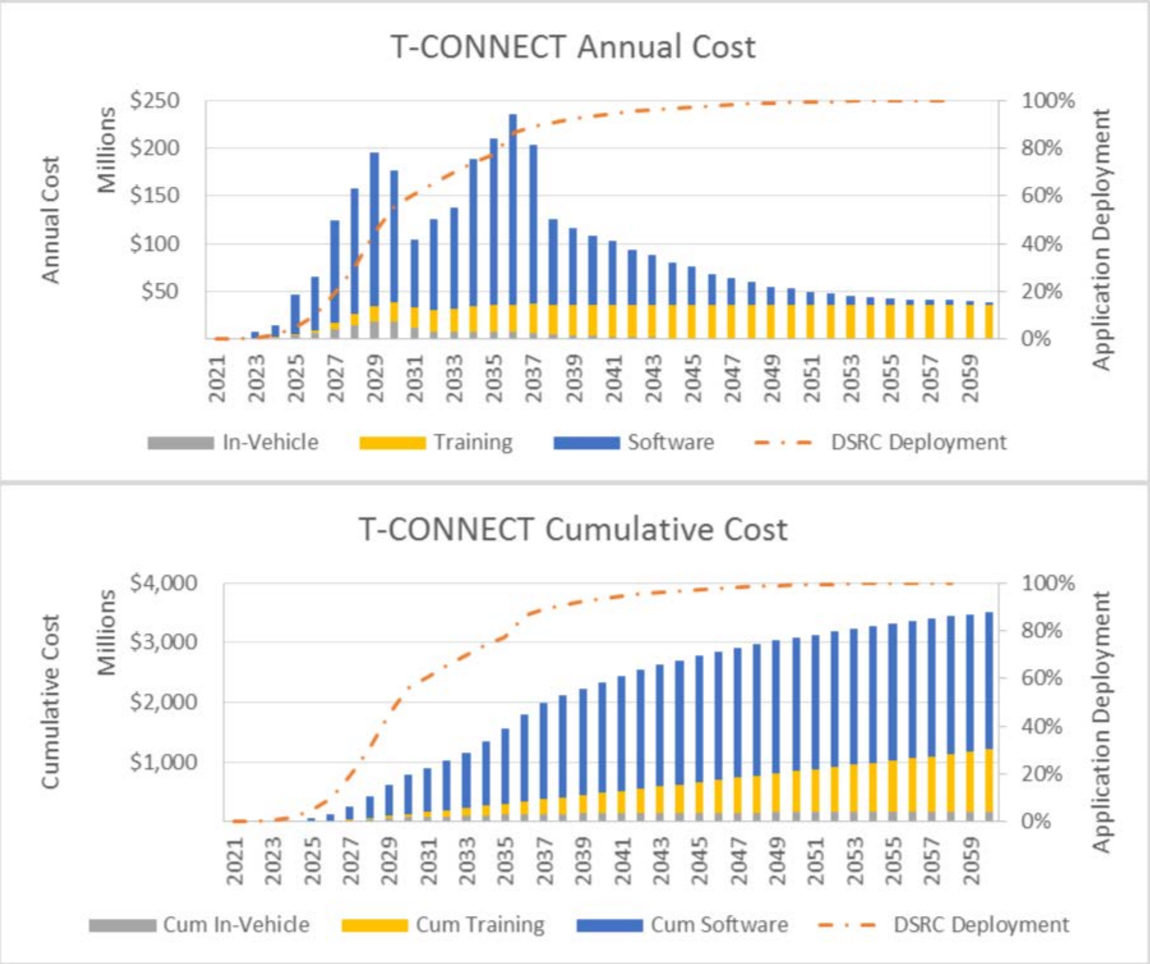
Table 17. IDTO Cost Breakdown Structure

WBS	BUILDING BLOCKS	Cost Type	T-CONNECT	T-DISP
1.1.	*Drivers for Transit Vehicles*		*TRUE*	*TRUE*
1.1.1.	*Driver Training Hours: Transit Vehicles*	*Training*	*TRUE*	*TRUE*
1.6.	*Signalized Intersections*			*TRUE*
1.6.1.	*Backhaul communications upgrade*	*Infrastructure*		*TRUE*
1.6.3.	*RSE Planning & Design*	*In-Vehicle*		*TRUE*
1.6.5.	*Roadside Equipment (RSEs)*	*Infrastructure*		*TRUE*
1.10.	*Freeway Segments*			*TRUE*
1.10.2.	*Backhaul communications upgrade*	*Infrastructure*		*TRUE*
1.10.4.	*RSE Planning & Design*	*In-Vehicle*		*TRUE*
1.10.5.	*Roadside Equipment (RSEs)*	*Infrastructure*		*TRUE*
1.14.	*Transit Vehicles*		*TRUE*	*TRUE*
1.14.1.	*Transit Retrofit kit / OBU*	*In-Vehicle*		*TRUE*
1.14.2.	*Transit software package*	*Software*	*TRUE*	*TRUE*
1.14.4.	*Mobile (cellular-based) carry-in device*	*In-Vehicle*	*TRUE*	*TRUE*
1.14.5.	*Mobile device cellular data plan for 12 months*	*In-Vehicle*	*TRUE*	*TRUE*
1.14.8.	*App for mobile device: T-Connect*	*In-Vehicle*	*TRUE*	
1.14.9.	*App for mobile device: T-Disp*	*In-Vehicle*		*TRUE*
1.16.	*Software Development*		*TRUE*	*TRUE*
1.16.11.	*Software Development & Testing: T-Connect*	*Software*	*TRUE*	
1.16.12.	*Software Development & Testing: T-Disp*	*Software*		*TRUE*

Source: Booz Allen Hamilton, June 2016

T-CONNECT: Below are the estimated annual and total cumulative cost results of deploying the T-CONNECT application on the national level considering cost sharing opportunities.

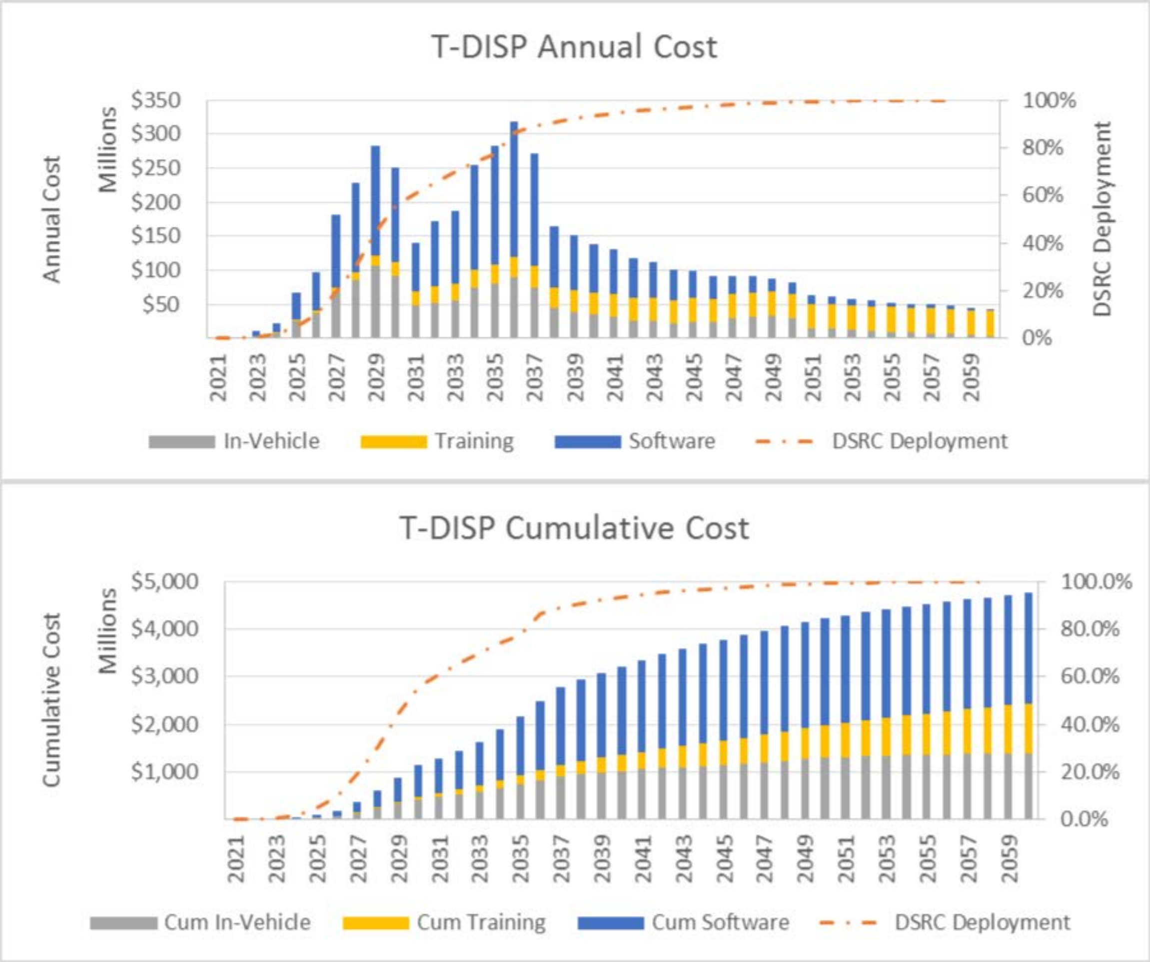
Figure 42. T-CONNECT Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

T-DISP: Below are the estimated annual and total cumulative cost results of deploying the T-DISP application on the national level considering cost sharing opportunities.

Figure 43. T-DISP Annual and Cumulative Application-Specific Cost



Source: Booz Allen Hamilton, June 2016

Chapter 5. Limitations of the Analysis

Baseline and Impacts Estimates: The impacts estimation makes several assumptions regarding the baseline. It treats the entire nation as a single system due to limited availability of data. This method does not capture the regional variations in implementation of the applications and their performance. Regional impacts assessments may provide better insights into the local impacts of the applications.

CV Deployment: The team had access to NHTSA's three different safety application deployment rates as a percent of DSRC-equipped vehicles. The upper, lower, and primary safety application deployment rates provided by NHTSA all converge by year 2030. The team assumed that the least aggressive rates of safety application deployment percentages are applicable to the DMA program since the mobility applications will likely follow the safety applications. The RSU curves and the application deployment curves were not used because they were not publicly available.

Compliance and Adoption: These factors influence the performance of applications. They were not considered separately in the analysis, but are in line with the bundles' IA results.

Sensitivity Analysis: Due to the restricted scope of the project, a sensitivity analysis was not carried out to test the sensitivity of impacts and costs to different future scenarios. Also, this study does not capture any synergies between applications that would eventually be deployed in conjunction.

Cost Estimates: The unit cost data, O&M costs, and useful life data are derived from the AASHTO LCC model based on the current state of knowledge. This data is limited and may not apply to the entire nation as it was used in the extrapolation of this analysis. To the extent that the unit costs, O&M costs, and useful life data are over- or under- estimated, the national estimates for the costs of deploying each application will also be over- or under- estimated.

Geographical Limitation: The analysis is limited since it assumes that the entire United States will incur the same costs and will deploy all of the applications based on the NHTSA deployment rates.

Chapter 6. Conclusions

Despite the limitations of the analysis, this study provides a rough order magnitude of the national mobility impacts and costs of a national deployment of the DMA applications.

From an impacts perspective, the analysis is based on the IA results of individual bundles that allow a quantification of the mobility impacts (on the basis of monetized travel time savings). However, some of the applications (e.g., SPD-HARM and Q-WARN) have important benefits under other impact areas outside of mobility despite the negligible to slightly negative impacts that they have on mobility. Therefore, an accurate and comprehensive assessment of those applications' impacts should take into account non-mobility benefits (e.g., safety and environmental benefits) as well.

From a cost perspective, this study looks at the comprehensive set of costs incurred for the national deployment of each application ('from the ground up'). This is a conservative assumption and, in reality, the DMA applications will leverage the existing CV environment and infrastructure, which leads to a more realistic and accurate cost estimation.

As those applications move from limited prototype tests to actual deployments, an accurate collection of cost data and performance measures will allow a more realistic benefits and costs computation that captures the real effect of DMA applications as they are deployed along with other CV applications in a certain area. Such a real-world assessment will further pinpoint synergies between applications, their combined impacts, and their actual deployment costs.

Chapter 7. References

References
“AMS Testbed Development and Evaluation to Support DMA and ATDM Programs - EnableATIS Evaluation on the Phoenix AMS Testbed,” *U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office,* May 2016.
“AMS Testbed Development and Evaluation to Support DMA and ATDM Programs - FRATIS Evaluation on the Phoenix AMS Testbed,” *U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office,* May 2016.
“AMS Testbed Development and Evaluation to Support DMA and ATDM Programs - T-DISP Evaluation on the Phoenix AMS Testbed,” *U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office,* May 2016.
“AMS Testbed Evaluation Report For DMA Program Draft Version 1.0,” *U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office,* December 2015.
“Estimated Benefits Of Connected Vehicle Applications: Dynamic Mobility Applications, AERIS V2I Safety, And Road Weather Management, Final Report,” *U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office.* August 20, 2015.
“Freight Advanced Traveler Information System (FRATIS) Impact Assessment, Final Report,” *U.S. Department of Transportation, Federal Highway Administration, Intelligent Transportation Systems Joint Program Office,* January 25, 2016.
“Transportation Energy Data Book, Edition 34,” *U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Oak Ridge National Laboratory*, September 2015, http://cta.ornl.gov/data/index.shtml.
“Manual on Uniform Traffic Control Devices. Frequently Asked Questions – Part 4 – Highway Traffic Signals,” *U.S. Department of Transportation, Federal Highway Administration,* http://mutcd.fhwa.dot.gov/knowledge/faqs/faq_part4.htm#tcsgq3.
“Summary of Travel Trends: 2009 National Household Travel Survey,” *U.S. Department of Transportation, Federal Highway Administration, Office of the Assistant Secretary for Research and Technology,* June 2011, http://nhts.ornl.gov/2009/pub/stt.pdf.
“System Design Document for the INFLO Prototype,” *U.S. Department of Transportation, Federal Highway Administration,* http://ntl.bts.gov/lib/54000/54800/54846/inflo-system-design-final-508-compliant_fhwa-jpo-14-169.pdf.
“Technical Report on Prototype Intelligent Network Flow Optimization (INFLO) Dynamic Speed Harmonization and Queue Warning,” *U.S. Department of Transportation, Research and Innovative Technology Administration Federal Highway Administration*, June 2015, http://ntl.bts.gov/lib/55000/55300/55304/100030614-601_technical_report_on_prototype_intelligent_network_flow_optimization_final_.pdf.
“Annual Vehicle Distance Traveled in Miles and Related Data – 2012 (1) By Highway Category and Vehicle Type,” *U.S. Department of Transportation, Federal Highway Administration*, January 2014, https://www.fhwa.dot.gov/policyinformation/statistics/2012/pdf/vm1.pdf.
“The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations, Revision 2,” *U.S. Department of Transportation*, September 2011, https://www.transportation.gov/sites/dot.dev/files/docs/vot_guidance_092811c.pdf.
“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), Final Report,” *U.S. Department of Transportation*, *Federal Highway Administration, Intelligent Transportation Systems Joint Program Office*, May 8, 2015.

“Impacts Assessment of Integrated Dynamic Transit Operations,” *U.S. Department of Transportation*, *Intelligent Transportation Systems Joint Program Office*, January 8, 2016.

“Impacts Assessment of Integrated Dynamic Transit Operations Addendum to Evaluation Plan,” *U.S. Department of Transportation*, *Intelligent Transportation Systems Joint Program Office*, February 3, 2016.

“Impacts Assessment of Dynamic Speed Harmonization with Queue Warning Task 3 IA Report Version 3.1,” *U.S. Department of Transportation*, *Intelligent Transportation Systems Joint Program Office*, June 2015, http://ntl.bts.gov/lib/55000/55300/55307/Impact_Assesment_Report_Final_2015.pdf.

“Multi Modal Intelligent Traffic Signal Systems Impacts Assessment Final Report,” *U.S. Department of Transportation*, *Intelligent Transportation Systems Joint Program Office*, August 2015.

“The AASHTO V2I Life Cycle Cost (LCC) Estimation Model,” *American Association of State Highway and Transportation Officials.*

The Cost Overview For Planning Ideas and Logical Organization Tool (CO-PILOT) Tool, *U.S. Department of Transportation*.

The Highway Policy Information Database, *U.S. Department of Transportation*.

The National Highway Traffic Safety Administration (NHTSA) Safety Application Deployment Curves, *U.S. Department of Transportation, National Highway Traffic Safety Administration.*

Chapter 8. Acronyms

ACRONYM	DEFINITION
AADT	Average Annual Daily Traffic
AASHTO	Association of State Highway and Transportation Officials
AMS	Analysis Modeling and Simulation
EnableATIS	Enable Advanced Traveler Information System
ATIS	Multimodal Real-Time Traveler Information System
BTS	Bureau of Transportation Statistics
CBS	Cost Breakdown Structure
ConOps	Concept of Operations
CO-PILOT	Cost Overview For Planning Ideas & Logical Organization Tool
CV	Connected Vehicle
DMA	Dynamic Mobility Applications
D-RIDE	Dynamic Ridesharing
DR-OPT	Drayage Optimization
DSRC	Dedicated Short Range Communications
EVAC	Emergency Communications and Evacuation
F-ATIS	Freight Real-Time Traveler Information with Performance Monitoring
F-DRG	Freight Dynamic Route Guidance
FMCSA	Federal Motor Carrier Safety Administration
FRATIS	Freight Advanced Traveler Information System
FSDTPP	Freight Specific Dynamic Travel Planning and Performance
FSP	Freight Signal Priority
IA	Impact Assessment
IDTO	Integrated Dynamic Transit Operations
IDTO-BET	Integrated Dynamic Transit Operations – Bundle Evaluation Tool
INC-ZONE	Incident Scene Work Zone Alerts For Drivers and Workers
INFLO	Include Intelligent Network Flow Optimization
INFLO	Intelligent Network Flow Optimization
I-SIG	Intelligent Traffic Signal System
ITE	Institute of Transpiration
LCC	Life Cycle Cost
MMITSS	Multi-Modal Intelligent Traffic Signal System
MUTCD	Manual On Uniform Traffic Control Devices
NDR	National Driver Register

ACRONYM	DEFINITION
NHTSA	National Highway Traffic Safety Administration
O&M	Operations and Maintenance
OMB	Office of Management and Budget
OSADP	Open Source Application Development Portal
PD	Prototype Development
PED-SIG	Mobile Accessible Pedestrian Signal System
PREEMPT	Emergency Vehicle Preemption
Q-WARN	Queue Warning
RSU	Roadside Unit
S-PARK	Smart Park-And-Ride
SPD-HARM	Dynamic Speed Harmonization
SyRs	System Requirements
T-CONNECT	Connection Protection
T-DISP	Dynamic Transit Operations
T-MAP	Universal Map Application
TSP	Transit Signal Priority
TT	Travel Time
USDOT	U.S. Department of Transportation
V2I	Vehicle To Infrastructure
V2I	Vehicle-To-Infrastructure
V2V	Vehicle-To-Vehicle
VMT	Vehicle Miles Traveled
WX-INFO	Real-Time Route-Specific Weather Information

Appendix A. AASHTO LCC - Sources of Cost Data

BuildingBlocks	Components	Source of Cost
Drivers for Public Safety Vehicles	Driver Training Hours: Public Safety Vehicles	CO-PILOT
Drivers for Transit Vehicles	Driver Training Hours: Transit Vehicles	CO-PILOT
Drivers for Trucks	Driver Training Hours: Trucks	CO-PILOT
Dynamic Speed Harmonization - DSRC (SPD-HARM)	Software Customization Cost: SPD-HARM	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Dynamic Transit Operations - Cellular (T-DISP)	Software Customization Cost: T-DISP	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Freight Drayage Optimization - Cellular (FDO)	Software Customization Cost: FDO	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Freight Drayage Optimization - DSRC (FDO)	Software Customization Cost: DR-OPT	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Freight Signal Priority - DSRC (FSP)	Software Customization Cost: FSP	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Freight Terminals	Inductive Loop Detectors	CO-PILOT
Freight Terminals	Roadside Equipment (RSEs)	CO-PILOT
Freight Terminals	RSE Planning & Design	CO-PILOT
Incident Scene Work Zone Alerts for Drivers and Workers - DSRC (INC-ZONE)	Software Customization Cost: INC-ZONE	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Intelligent Traffic Signal System - DSRC (I-SIG)	Software Customization Cost: I-SIG	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
ITS Roadway Equipment	Roadside Equipment (RSEs)	CO-PILOT
ITS Roadway Equipment	RSE Planning & Design	CO-PILOT
Public Safety Vehicles	App for mobile device: INC-ZONE	CO-PILOT
Public Safety Vehicles	Public safety vehicle retrofit kit/OBU	CO-PILOT
Public Safety Vehicles	Public safety vehicle software package	CO-PILOT
Queue Warning - Cellular (Q-WARN)	Software Customization Cost: Q-WARN	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Road Segments	Backhaul communications upgrade	CO-PILOT
Road Segments	Inductive Loop Detectors	CO-PILOT
Road Segments	Pucks (Sub-surface temperature sensors)	CO-PILOT
Road Segments	Roadside Equipment (RSEs)	CO-PILOT
Road Segments	RSE Planning & Design	CO-PILOT
Road Segments	Road Weather Information System (RWIS) pavement and atmospheric sensor system	CO-PILOT (Mode Value of $26k) & Project Evaluation Team Review: Minnesota Department of Transportation (Max value of $100k)
Road Segments	CCTV Camera	RITA ITS: http://www.itscosts.its.dot.gov/its/benecost.nsf/DisplayRUCByUnitCostElementUnadjusted?ReadForm&UnitCostElement=CCTV+Video+Camera&Subsystem=Roadside+Detection+(RS-D)
Road Segments	Dynamic Message Sign	RITA ITS: http://www.itscosts.its.dot.gov/its/benecost.nsf/SubsystemCostsAdjusted?OpenForm&Subsystem=Roadside+Information+(RS-I) (average of actual values) & http://www.itscosts.its.dot.gov/its/benecost.nsf/DisplayRUCByUnitCostElementUnadjusted?ReadForm&UnitCostElement=Dynamic+Message+Sign&Subsystem=Roadside+Information+(RS-I)

BuildingBlocks	Components	Source of Cost
Signalized Intersections	Backhaul communications upgrade	CO-PILOT
Signalized Intersections	Inductive Loop Detectors	CO-PILOT
Signalized Intersections	Optical Detection System	CO-PILOT
Signalized Intersections	Pucks (Sub-surface temperature sensors)	CO-PILOT
Signalized Intersections	Roadside Equipment (RSEs)	CO-PILOT
Signalized Intersections	RSE Planning & Design	CO-PILOT
Signalized Intersections	Signal controllers	CO-PILOT
Signalized Intersections	Road Weather Information System (RWIS) pavement and atmospheric sensor system	CO-PILOT (Mode Value of $26k) & Project Evaluation Team Review: Minnesota Department of Transportation (Max value of $100k)
Signalized Intersections	CCTV Camera	RITA ITS: http://www.itscosts.its.dot.gov/its/benecost.nsf/DisplayRUCByUnitCostElementUnadjusted?ReadForm&UnitCostElement=CCTV+Video+Camera&Subsystem=Roadside+Detection+(RS-D)
Transit Signal Priority - DSRC (TSP)	Software Customization Cost: TSP	Project Evaluation Team (PET) Review: Minnesota Department of Transportation
Transit Vehicles	App for mobile device: FDO	CO-PILOT
Transit Vehicles	App for mobile device: INC-ZONE	CO-PILOT
Transit Vehicles	App for mobile device: Q-WARN	CO-PILOT
Transit Vehicles	App for mobile device: SPD-HARM	CO-PILOT
Transit Vehicles	App for mobile device: T-DISP	CO-PILOT
Transit Vehicles	Transit Retrofit Kit/ OBU	CO-PILOT
Transit Vehicles	Transit software package	CO-PILOT
Transit Vehicles	Mobile (cellular-based) carry-in device	Forbes: http://www.forbes.com/sites/tristanlouis/2013/09/14/the-real-cost-of-a-smartphone/
Transit Vehicles	Mobile device cellular data plan (for 12 months)	http://www.itscosts.its.dot.gov/ITS/benecost.nsf/SummID/SC2014-00330?OpenDocument&Query=Home (at the bottom of the page) & CO-PILOT (Pro-rated to twelve months) & http://www.forbes.com/sites/tristanlouis/2013/09/22/the-real-price-of-wireless-data/
Trucks	App for mobile device: DR-OPT	CO-PILOT
Trucks	App for mobile device: INC-ZONE	CO-PILOT
Trucks	App for mobile device: Q-WARN	CO-PILOT
Trucks	App for mobile device: SPD-HARM	CO-PILOT
Trucks	Truck Retrofit kit / OBU	CO-PILOT
Trucks	Truck software package	CO-PILOT
Trucks	Mobile (cellular-based) carry-in device	Forbes: http://www.forbes.com/sites/tristanlouis/2013/09/14/the-real-cost-of-a-smartphone/
Trucks	Mobile device cellular data plan (for 12 months)	http://www.itscosts.its.dot.gov/ITS/benecost.nsf/SummID/SC2014-00330?OpenDocument&Query=Home (at the bottom of the page) & CO-PILOT (Pro-rated to twelve months) & http://www.forbes.com/sites/tristanlouis/2013/09/22/the-real-price-of-wireless-data/

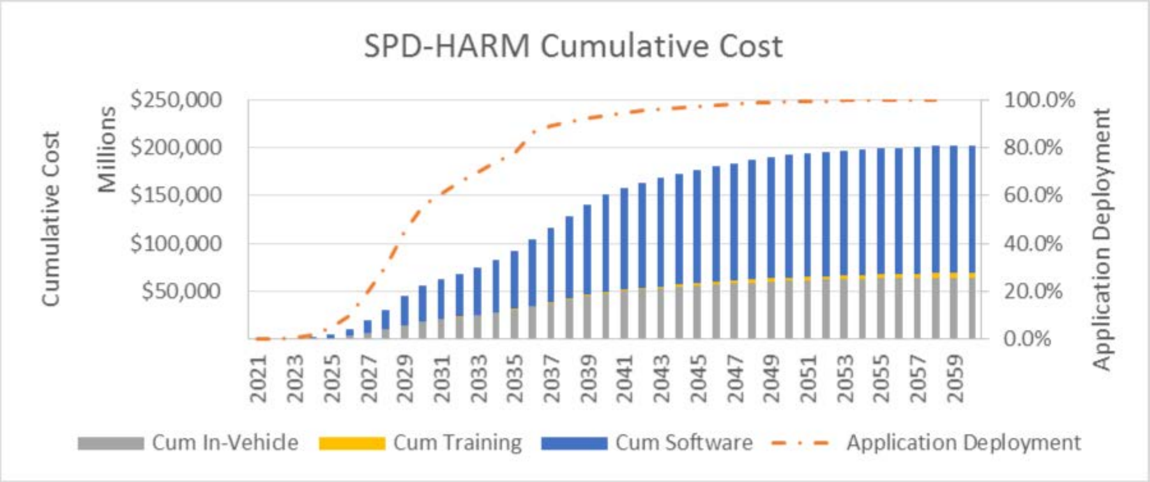
Appendix B. Application-Specific Costs with No Cost Sharing Results

The charts below summarize the overall “in-vehicle”, “training”, and “software” costs of each application assuming that each application will require its own specific (and exclusive) equipment/software. Even though many applications will be able to utilize the same on-board equipment, off-the shelf software development, or potential combined training sessions, these charts demonstrate a conservative scenario with no cost sharing opportunities. These charts are intended to provide an insight into the national level implementation costs of individual applications in the absence of any other application.

Intelligent Network Flow Optimization (INFLO) Bundle

Dynamic Speed Harmonization (SPD-HARM)

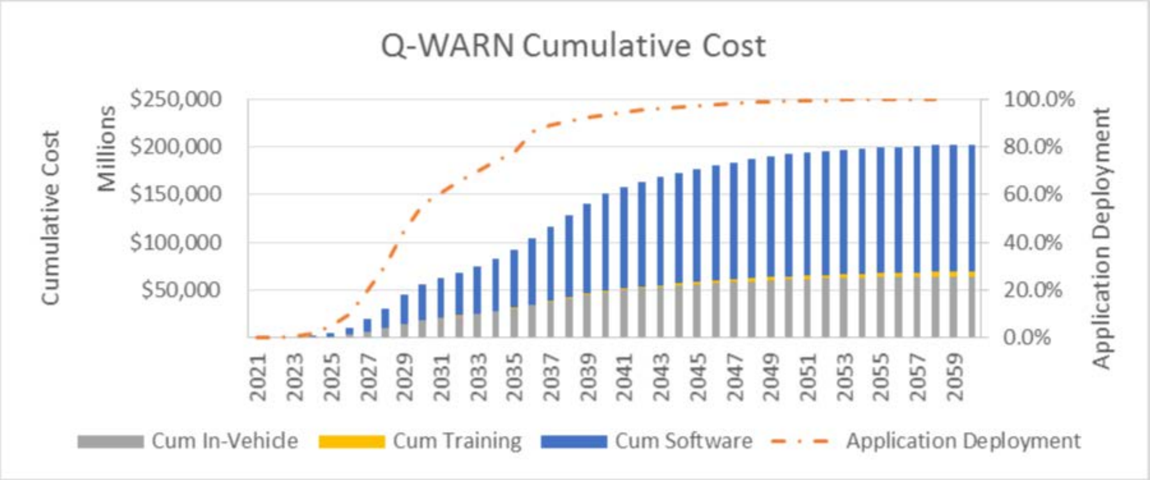
Figure 44. SPD-HARM Cumulative Application-Specific Cost Without Cost Sharing



Source: Booz Allen Hamilton, June 2016

Queue Warning (Q-WARN)

Figure 45. Q-WARN Cumulative Application-Specific Cost Without Cost Sharing

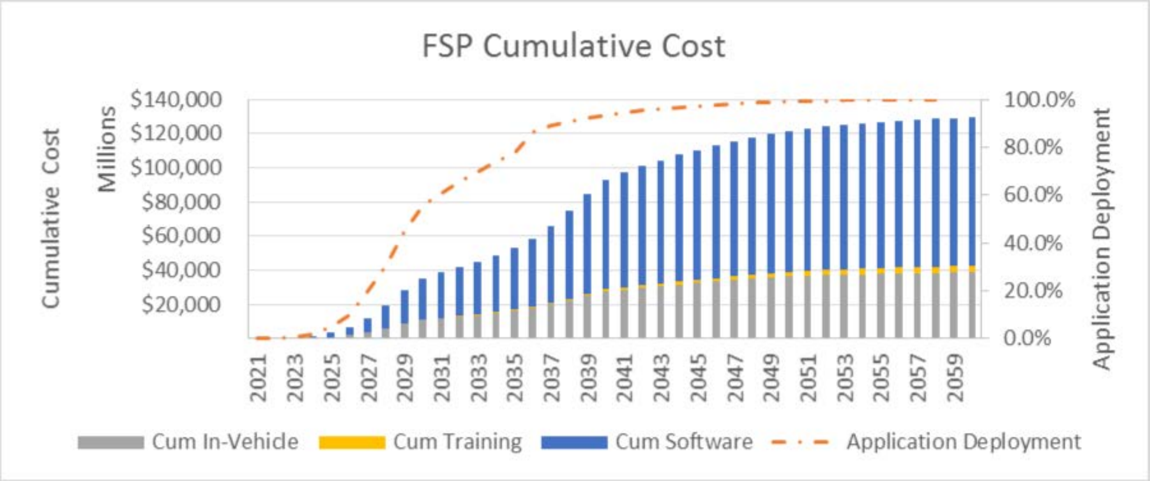


Source: Booz Allen Hamilton, June 2016

Multi-Modal Intelligent Traffic Signal System (MMITSS)

Freight Signal Priority (FSP)

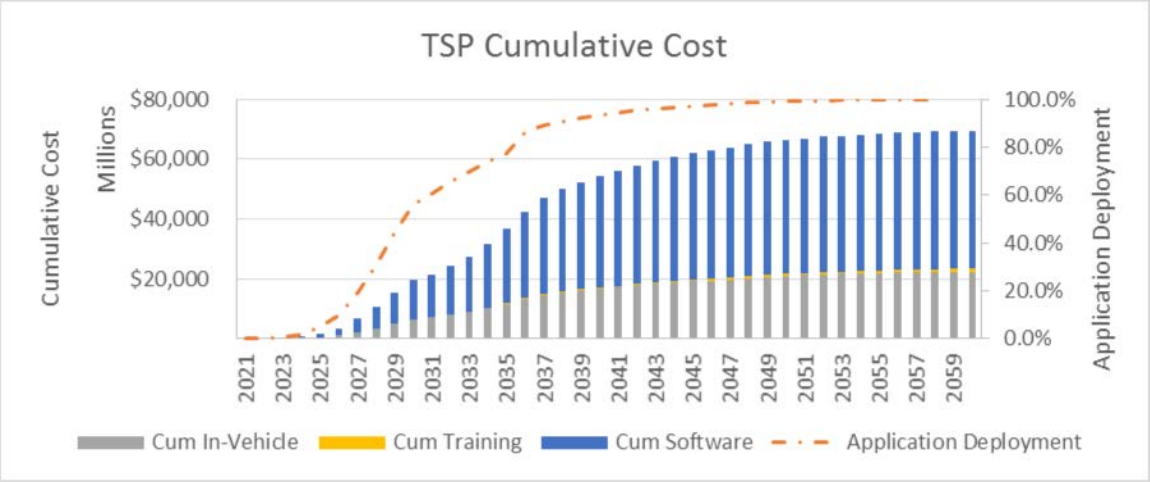
Figure 46. FSP Cumulative Application-Specific Cost Without Cost Sharing



Source: Booz Allen Hamilton, June 2016

Transit Signal Priority (TSP)

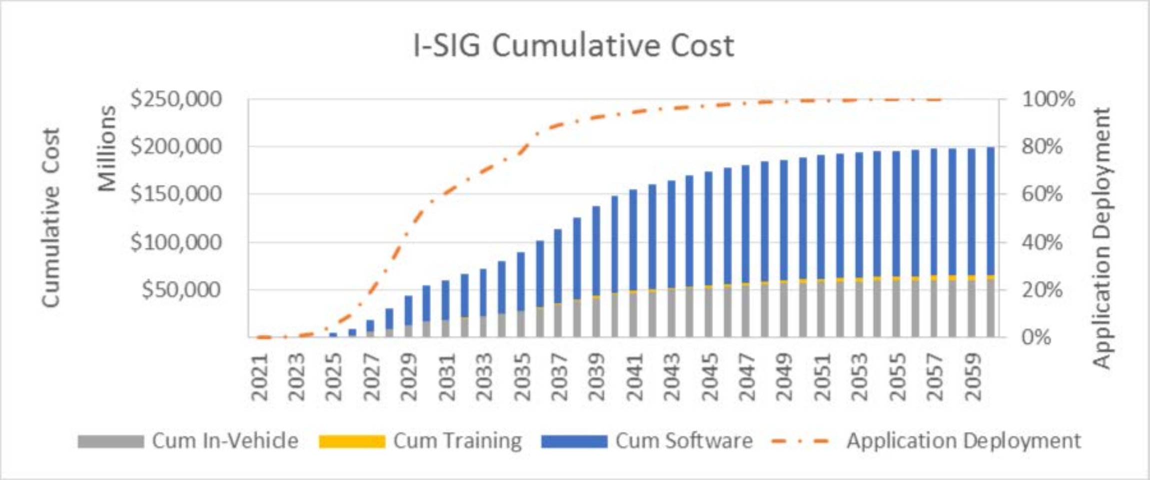
Figure 47. TSP Cumulative Application-Specific Cost Without Cost Sharing



Source: Booz Allen Hamilton, June 2016

Intelligent Traffic Signal System (I-SIG)

Figure 48. I-SIG Cumulative Application-Specific Cost Without Cost Sharing

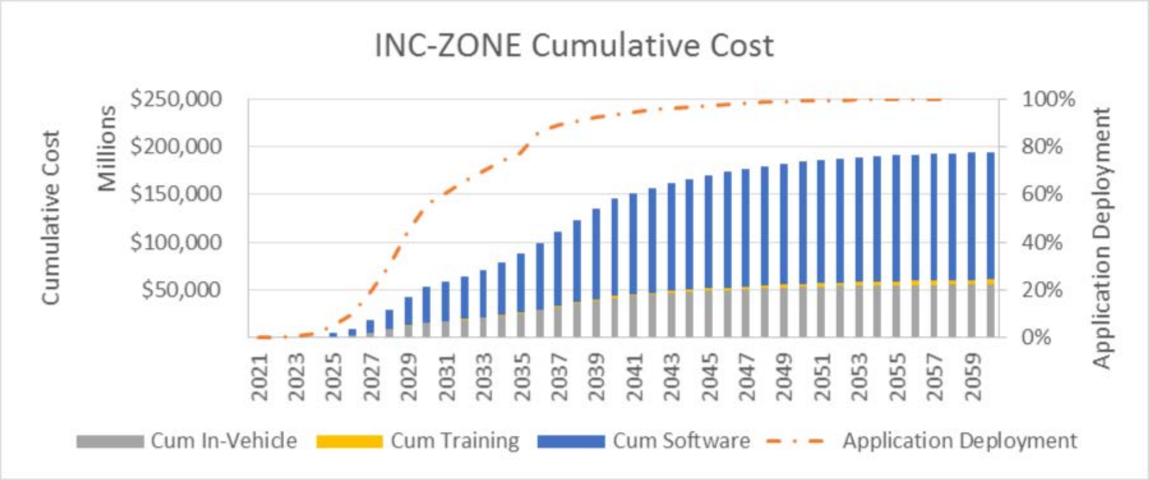


Source: Booz Allen Hamilton, June 2016

Response, Emergency Staging and Communication, Uniform Management, and Evaluation (R.E.S.C.U.M.E.)

Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)

Figure 49. INC-ZONE Cumulative Application-Specific Cost Without Cost Sharing

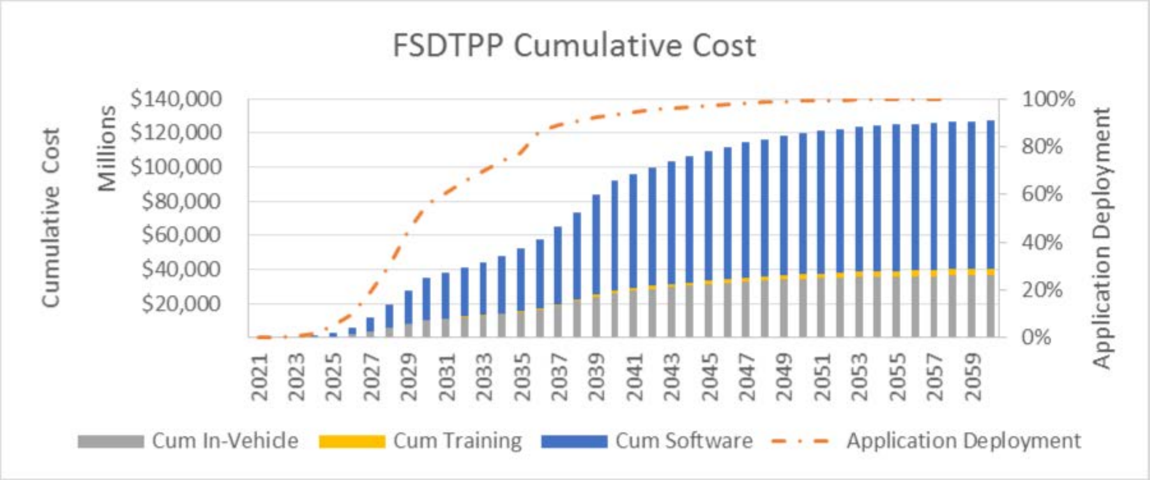


Source: Booz Allen Hamilton, June 2016

Freight Advanced Traveler Information System (FRATIS)

Freight Specific Dynamic Travel Planning and Performance (FSDTPP)

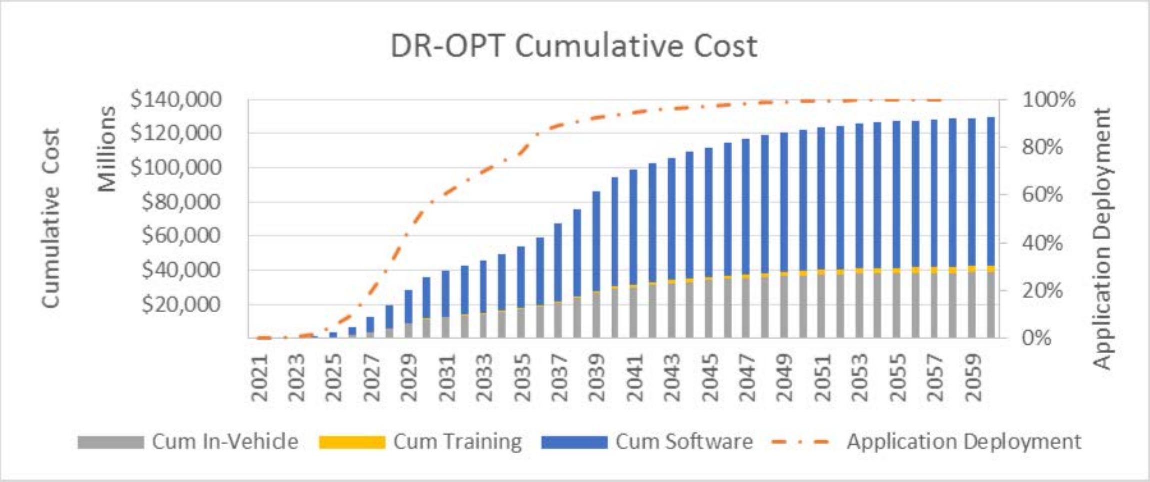
Figure 50. FSDTPP Cumulative Application-Specific Cost Without Cost Sharing



Source: Booz Allen Hamilton, June 2016

Drayage Optimization (DR-OPT)

Figure 51. DR-OPT Cumulative Application-Specific Cost Without Cost Sharing

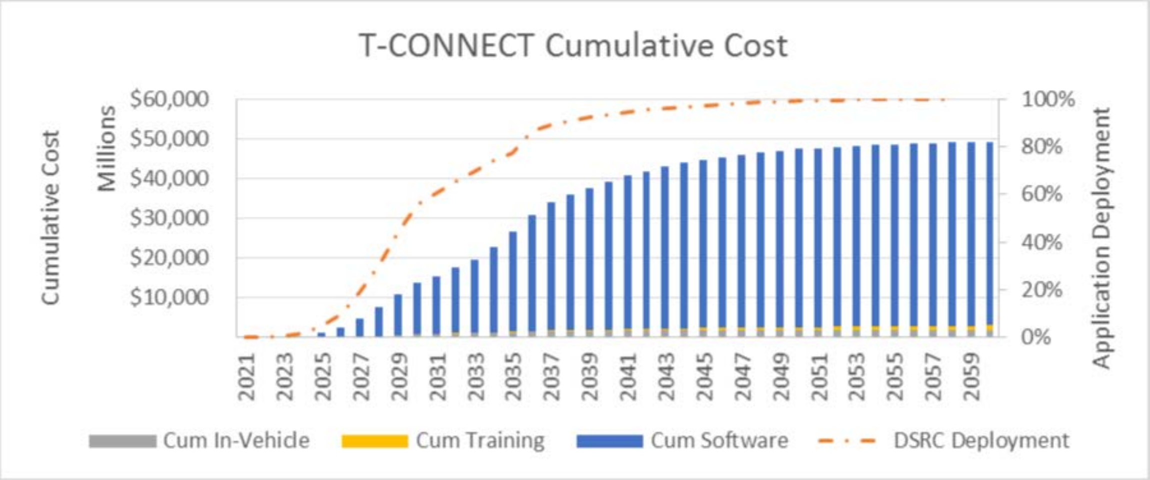


Source: Booz Allen Hamilton, June 2016

Integrated Dynamic Transit Operations (IDTO)

T-CONNECT

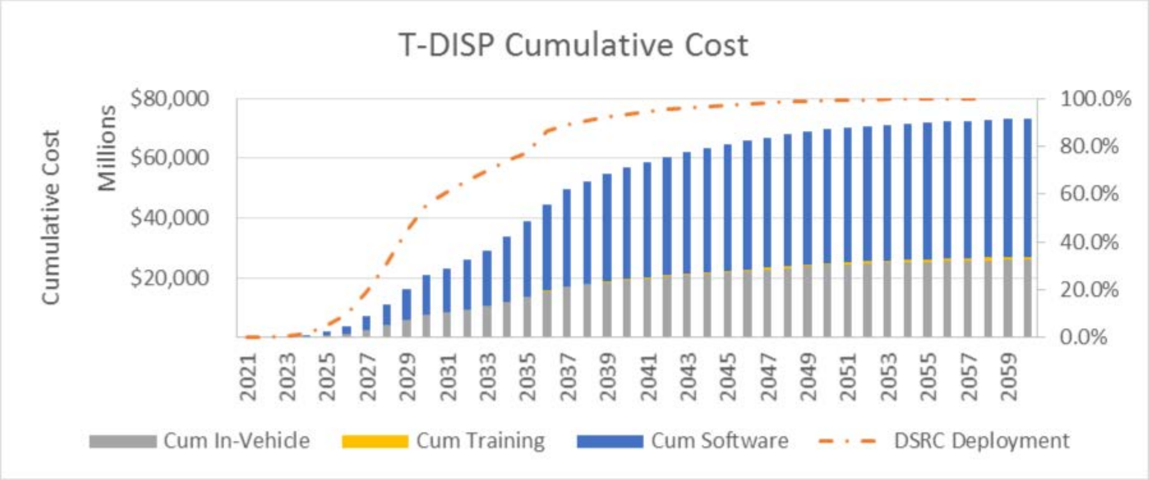
Figure 52. T-CONNECT Cumulative Application-Specific Cost Without Cost Sharing



Source: Booz Allen Hamilton, June 2016

T-DISP

Figure 53. T-DISP Cumulative Application-Specific Cost Without Cost Sharing



Source: Booz Allen Hamilton, June 2016

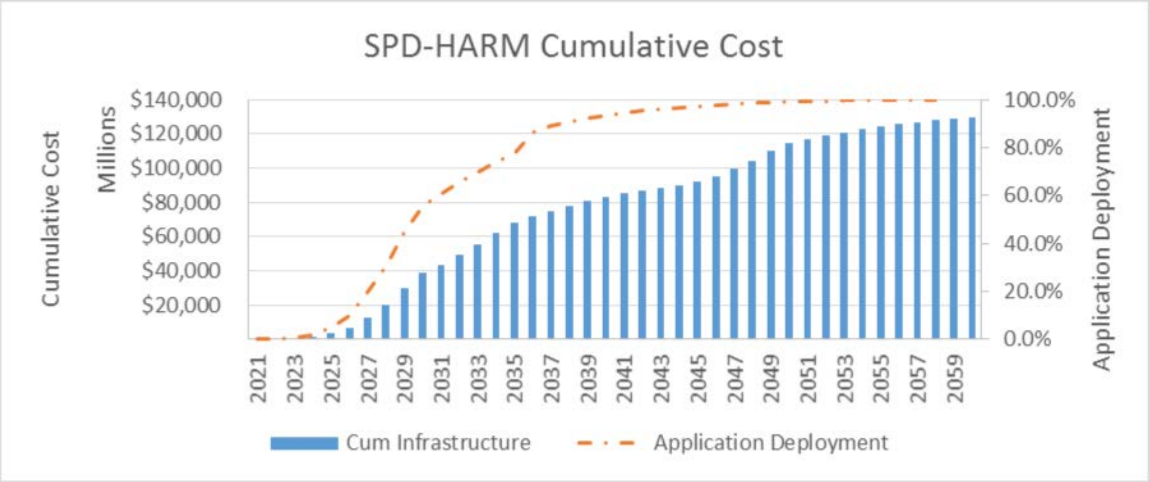
Appendix C. Application-Specific Infrastructure Cost Results

The charts below include the overall “infrastructure” cost necessary for deployment of each application. This type of chart is intended to demonstrate the “worst case scenario” from a costing perspective in which the entire infrastructure has to be put in place before the deployment of the application in the entire nation. Even though this scenario is not realistic, it helps provide a rough order of magnitude cost estimation for the decision makers and agencies. In reality, much of the current CV infrastructure will be utilized and different applications will be able to leverage from the same infrastructure components and communication networks. Also, this scenario is conservative since it assumes all the corridors and regions in the United States will be equipped with the necessary infrastructure to support all of the DMA applications discussed in this analysis.

Intelligent Network Flow Optimization (INFLO) Bundle

Dynamic Speed Harmonization (SPD-HARM)

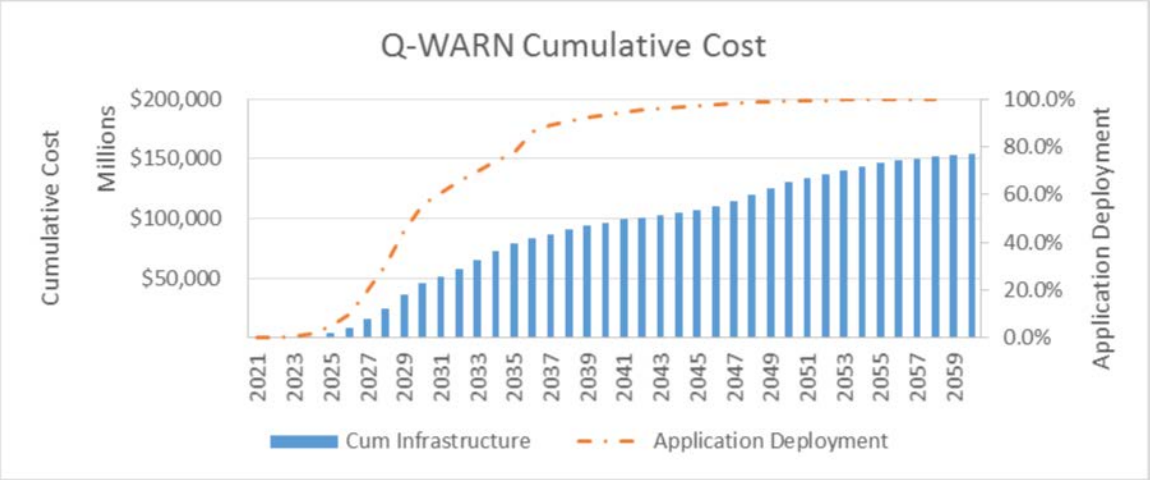
Figure 54. SPD-HARM Cumulative Infrastructure Cost



Source: Booz Allen Hamilton, June 2016

Queue Warning (Q-WARN)

Figure 55. Q-WARN Cumulative Infrastructure Cost

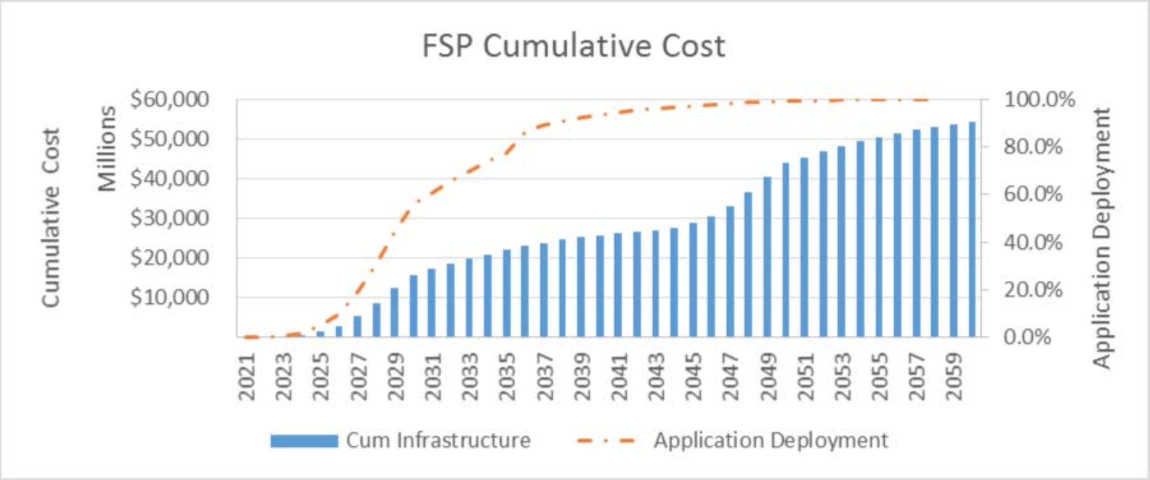


Source: Booz Allen Hamilton, June 2016

Multi-Modal Intelligent Traffic Signal System (MMITSS)

Freight Signal Priority (FSP)

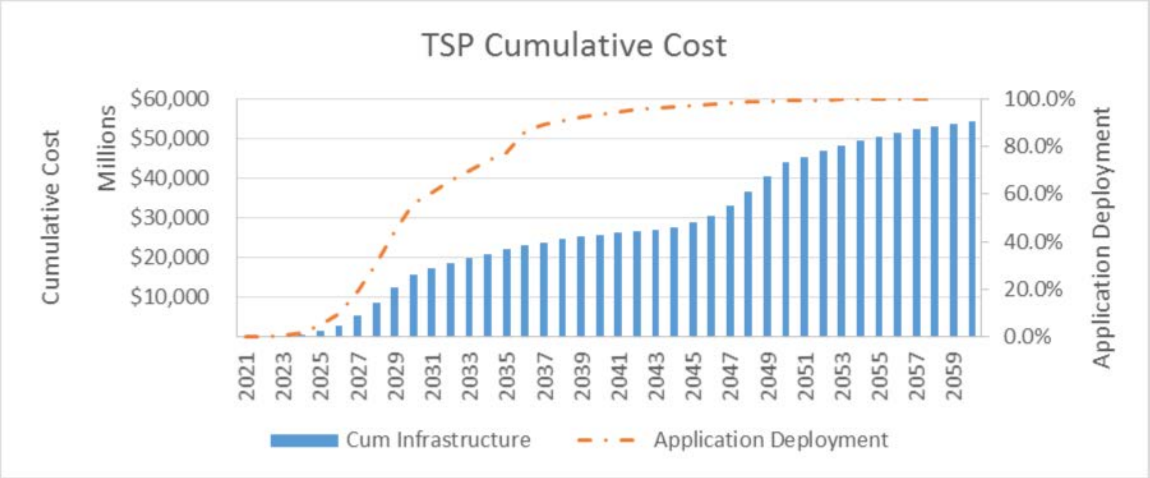
Figure 56. FSP Cumulative Infrastructure Cost



Source: Booz Allen Hamilton, June 2016

Transit Signal Priority (TSP)

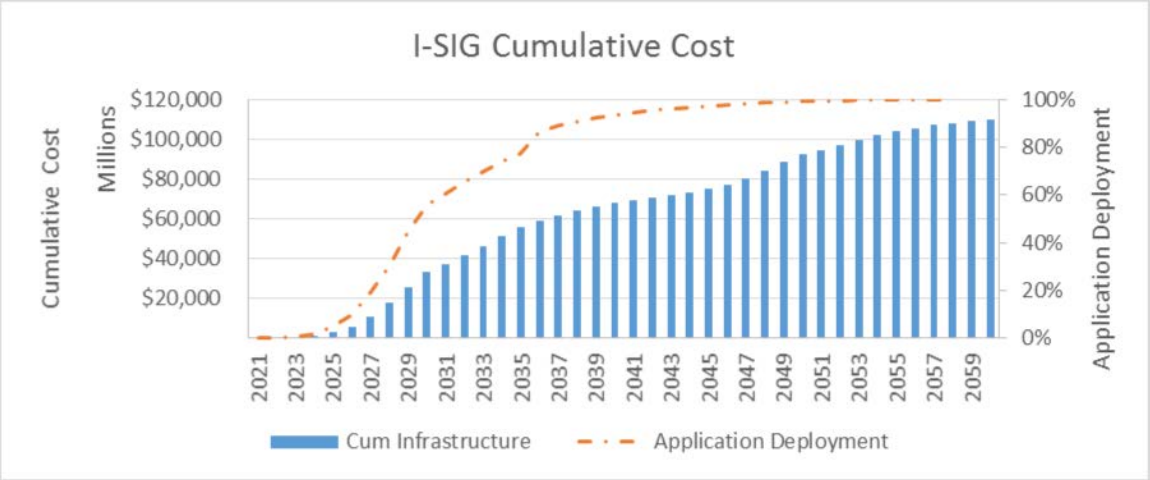
Figure 57. TSP Cumulative Infrastructure Cost



Source: Booz Allen Hamilton, June 2016

Intelligent Traffic Signal System (I-SIG)

Figure 58. I-SIG Cumulative Infrastructure Cost

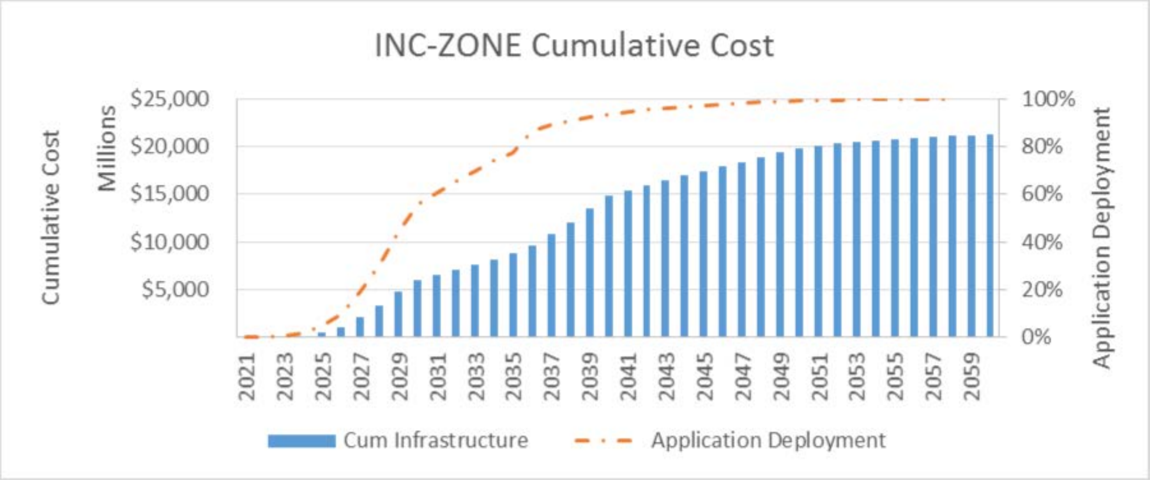


Source: Booz Allen Hamilton, June 2016

Response, Emergency Staging and Communication, Uniform Management, and Evaluation (R.E.S.C.U.M.E.)

Incident Scene Work Zone Alerts (INC-ZONE)

Figure 59. INC-ZONE Cumulative Infrastructure Cost

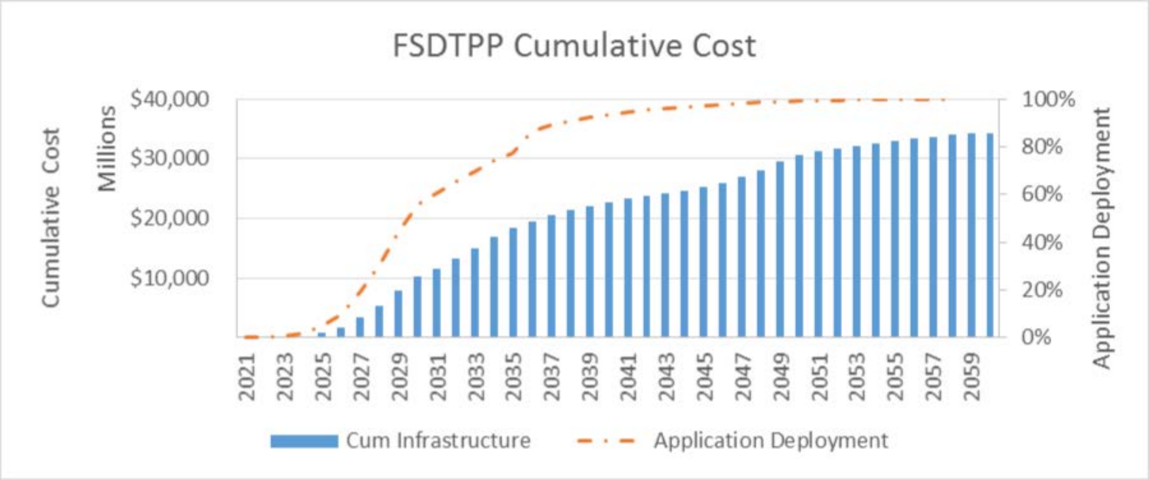


Source: Booz Allen Hamilton, June 2016

Freight Advanced Traveler Information System (FRATIS)

Freight Specific Dynamic Travel Planning and Performance (FSDTPP)

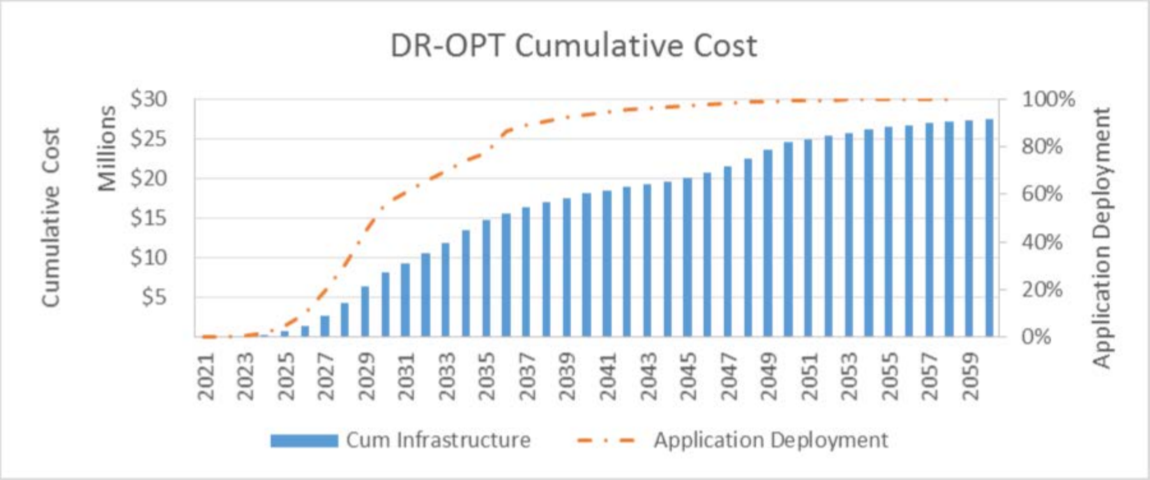
Figure 60. FSDTPP Cumulative Infrastructure Cost



Source: Booz Allen Hamilton, June 2016

Drayage Optimization (DR-OPT)

Figure 61. DR-OPT Cumulative Infrastructure Cost



Source: Booz Allen Hamilton, June 2016

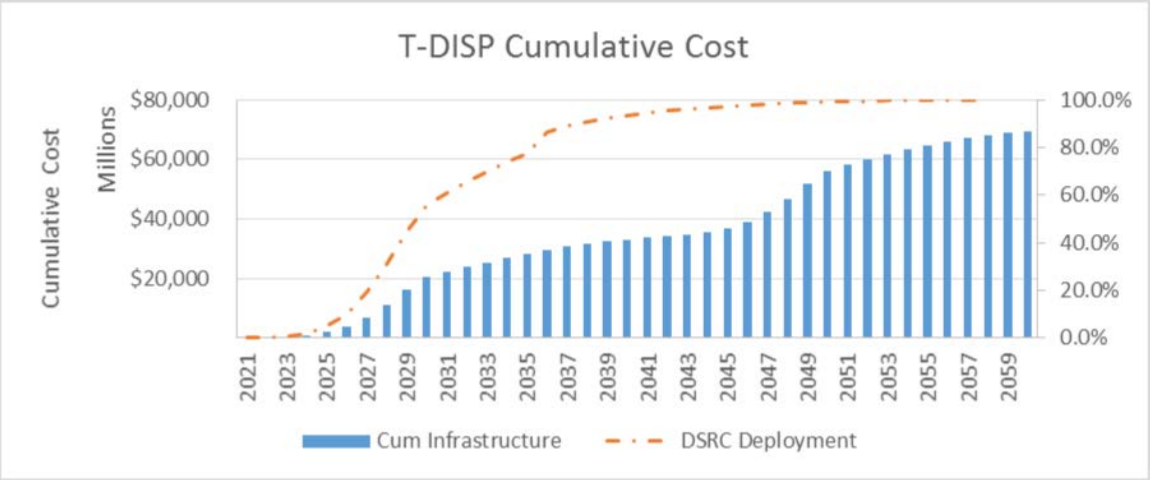
Integrated Dynamic Transit Operations (IDTO)

T-CONNECT

No infrastructure costs associated with T-CONNECT application.

T-DISP

Figure 62. T-DISP Cumulative Infrastructure Cost



Source: Booz Allen Hamilton, June 2016

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487
www.its.dot.gov

FHWA-JPO-16-419

U.S. Department of Transportation