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Federal Highway Administration
Office of the Assistant Secretary for Research and Technology

ROAD WEATHER CONNECTED VEHICLE APPLICATIONS

Benefit-Cost Analysis

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Interim Report — January 11, 2013

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Paul Pisano, RWMP Team Lead

16. Abstract
RWMP is currently engaged in a project to evaluate the potential benefits of road weather connected vehicle applications. Of particular interest are the potential improvements in safety, reductions in travel time, improved travel reliability, reductions to environmental impacts related to road treatment, and other possible benefits. The project includes the development of road weather connected vehicle applications concept of operations and benefit-cost analysis (BCA) of those applications. The concept of operations was completed and is documented in a companion report entitled "Concept of Operations for Road Weather Connected Vehicle Applications". The BCA was conducted in two phases; Phase I focused on evaluating safety benefits and Phase II evaluates the additional benefits including mobility, reductions in environmental impacts, and reductions in operational costs.

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The RWMP and its contractors have worked collaboratively to develop an approach to conduct a benefit-cost analysis of the road weather connected vehicle applications to identify the associated safety, mobility, environmental, and operational savings benefits.

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Introduction

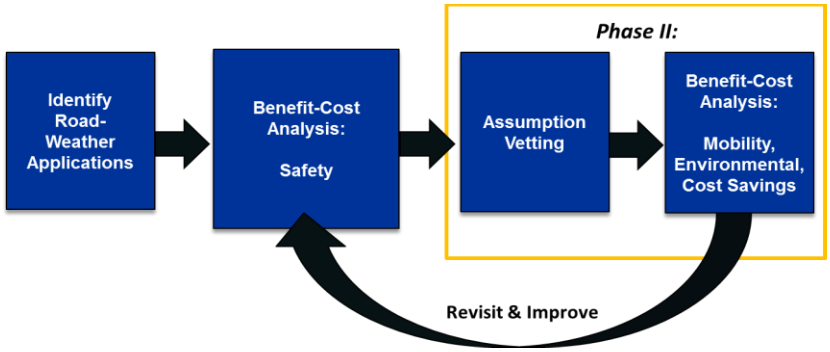
Program Overview

The Federal Highway Administration (FHWA) Road Weather Management Program (RWMP), within the Office of Operations, seeks to better understand the impacts of weather on roadways, and promote strategies and tools to mitigate those impacts. Envisioned is a system that provides "Anytime, Anywhere Road Weather Information" for road users and road operating agencies, as well as a robust, competitive market for road weather services. The RWMP is engaged in a number of activities to achieve these objectives including: stakeholder coordination; road weather research and development; technology transfer, training, and education; and performance management and evaluation. RWMP is currently evaluating the capability of connected vehicle technology to improve the collection, dissemination, and application of road weather data to reduce weather related crashes.

Project Overview

RWMP is currently engaged in a project to evaluate the potential benefits of road weather connected vehicle applications. Of particular interest are the potential improvements in safety, reductions in travel time, improved travel reliability, reductions to environmental impacts related to road treatment, and other possible benefits. The project includes the development of road weather connected vehicle applications concept of operations and benefit-cost analysis (BCA) of those applications. The concept of operations was completed and is documented in a companion report entitled "Concept of Operations for Road Weather Connected Vehicle Applications". The BCA was conducted in two phases; Phase I focused on evaluating safety benefits and Phase II evaluates the additional benefits including mobility, reductions in environmental impacts, and reductions in operational costs. Figure 1 provides a high level overview of the project and the role of the BCA.

Figure 1. Role of Benefit-Cost Analysis



Source: Booz Allen Hamilton, January 2013.

Road Weather Connected Vehicle Applications

There were seven road weather connected vehicle applications defined in the concept of operations. The applications were identified and fully defined in the companion report "Concept of Operations for Road Weather Connected Vehicle Applications" and are briefly described in Table 1 below.

Table 1. Road Weather Connected Vehicle Application Descriptions

Application	Description
Enhanced Maintenance Decision Support System	Road-weather connected vehicle data from snow plows, other agency fleet vehicles, and other vehicles operated by the general public provide input data to Enhanced-MDSS, resulting in improved maintenance operations and increased safety.
Information for Maintenance and Fleet Management Systems	Road-weather connected vehicle data are key inputs to Maintenance and Fleet Management Systems and can, in turn, be passed to an Enhanced-MDSS to refine the recommended winter weather response plans and treatment strategies.
Variable Speed Limits for Weather-Responsive Traffic Management	Road-weather connected vehicle data can be used to inform Variable Speed Limits systems to provide real-time information on appropriate speeds for current conditions and warn drivers of coming road conditions; this application is envisioned in particular in work zones during adverse driving conditions.
Motorist Advisories and Warnings	Road-weather connected vehicle data will provide advanced warning on deteriorating road and weather conditions on specific roadway segments to travelers pre-trip and en-route.
Information for Freight Carriers	Road-weather connected vehicle data will provide information on deteriorating road and weather conditions on specific roadway segments to both truck drivers and their dispatchers. This information can be used to improve scheduling decisions and parking availability and delivery schedules.
Information and Routing Support for Emergency Responders	Road-weather connected vehicle data will provide emergency responders, including ambulance operators, paramedics, and fire and rescue companies road-weather alerts and warnings. Road-weather conditions, especially road or lane closures due to snow, flooding, and wind-blown debris, for specific roadway segments will be used to determine response routes, calculate response times, and inform decisions to hand-off emergency calls from one responder to another in a different location.
Weather Responsive Signal Timing	Road-weather connected vehicle data is used by signals to optimize timing for safety and mobility during adverse weather conditions.

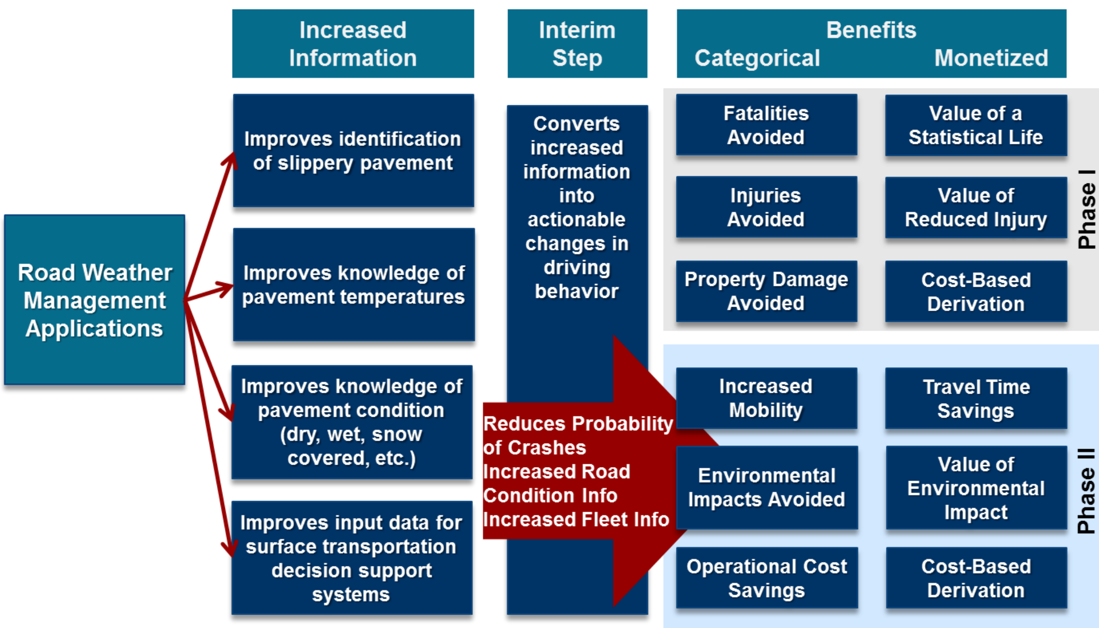
Source: Booz Allen Hamilton, January 2013.

Overview of the Benefit-Cost Analysis

The current effort comprises a high-level, benefit-cost analysis (BCA) that evaluates the seven road weather connected vehicle applications. One of the primary goals of the RWMP is to reduce the negative safety impacts of crashes that occur under adverse weather conditions. Therefore, the scope of the Phase I BCA is to evaluate the number of crashes that can potentially be avoided as a result of the implementation of the applications and the safety benefits that reduced crashes will in turn yield. Safety benefits within the scope of the analysis are: fatalities avoided, injuries avoided, and property damage avoided (includes both infrastructure and vehicle damage).

In addition to the primary safety goals of the RWMP, the potential non-safety benefits are also objectives of the Program. The scope of the Phase II BCA is to evaluate these benefits including improved mobility, reduced environmental impacts, and operational cost savings that can potentially be produced as a result of the implementation of the applications. Figure two provides an overview of the direct impacts of the applications and the secondary impacts that are considered in the BCA.

Figure 2. Primary and Secondary Benefits of Road Weather Connected Vehicle Applications



Source: Booz Allen Hamilton, January 2013.

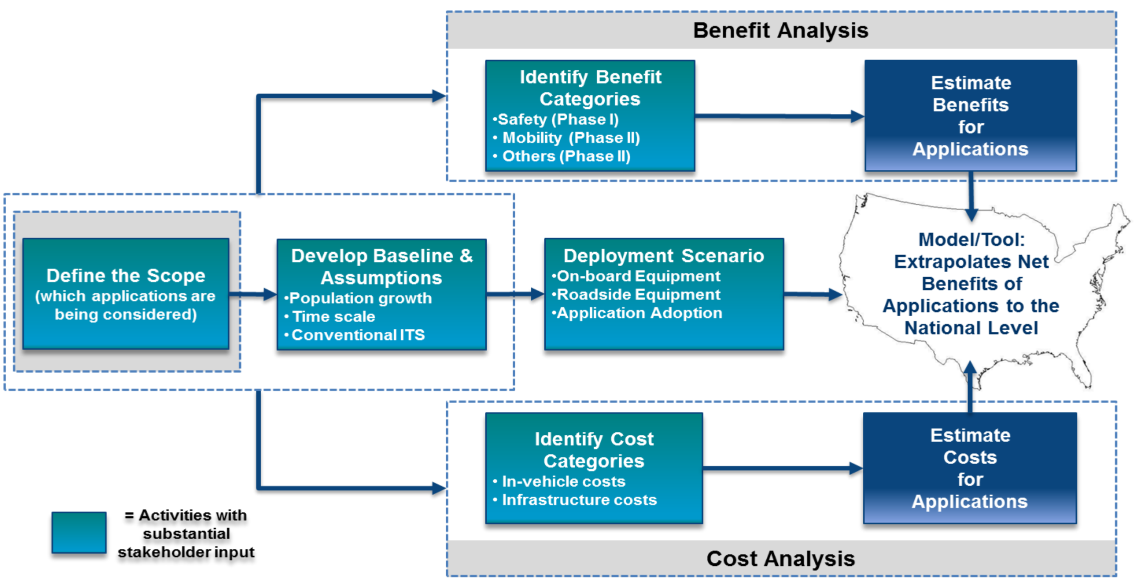
As the figure illustrates, the applications are expected to provide and leverage additional information about the condition of the road including slickness, temperature, wetness, etc. This information, along with driver alerts and infrastructure optimization for conditions, will lead to reduced crashes, increased roadway condition information, and increased information about fleets – the direct benefits of the applications. As a result of reduced crashes, the applications may lead to increased mobility and reduced environmental impacts as a result of decreased incident related congestion. More detailed data on road conditions will have operational cost savings and also decrease the environmental impacts of road treatment while maintaining the same level of service. Increased information on road conditions will also provide information to drivers on road capacity and help to optimize traffic flow through areas where capacity may be limited. Finally, increased information on the weather management fleet will provide operational cost savings. Each of these benefits is estimated and monetized utilizing standard practices (this will be discussed in more detail in the benefit estimation section).

The total costs of the deployment of the road weather applications including the connected vehicle environment (CVE) core, road weather management specific investments, and the application specific capital and operating and management costs are estimated. Detailed information on the costs will be described in the cost estimation section.

The BCA employs a systematic approach to evaluate the applications. Figure three below provides an overview. The applications were defined prior to initiating the BCA. The next step is to evaluate the baseline or the current impacts of adverse weather conditions on mobility, the environment, and operational costs associated with road weather maintenance. The baseline includes all current road weather management practices; the conventional intelligent transportation systems (ITS) road weather applications benefits to current road capabilities. The baseline provides the basis for which the benefits and costs of the applications can be compared against.

Additional significant components of the baseline are the time scale of the analysis and the geographic scope. For the purposes of the current analysis a 40-year period (2015-2055) is used to capture the benefits and costs of the applications; this moderately long time horizon was chosen due to the nature of deployment of connected vehicle technology. The geographic scope is limited to the benefits and costs of the road weather applications deployment within the United States.

Figure 3. Overview of the Benefit-Cost Analysis Approach



Source: Booz Allen Hamilton, January 2013.

With the baseline defined, the next step is to define the deployment scenario, this is the profile of when CVE will become available (e.g., 50% of vehicles will be connected in 2027). The deployment scenario also considers the adoption of the applications themselves (e.g., 15% of Transportation Management Centers (TMC) will implement the Variable Speed Limits for Weather-Responsive Traffic Management application in the near term). The deployment scenario also takes into account an "Application Maturity Effectiveness Factor" which estimates the effectiveness of the applications (i.e., the benefits realized) based on the level of CVE deployment. All of these factors will be described in greater detail in the deployment scenario section.

Benefit and cost estimation are conducted in parallel work streams. Utilizing the best available data from current literature, the efficacy and incidence for each of the applications is estimated. This provides a total potential increase in mobility, decrease in environmental impacts, and decrease in operational costs. Similarly, cost estimation uses literature and market research to determine capital and operating costs for prospective technologies that are required for the core CVE, road weather management specific investments, and the application specific capital and operating and management costs. These values are estimated on a per unit basis which will vary depending on the specific cost element (e.g., there is a unit price associated with the installation and operation for each on-board equipment unit).

The final step in the BCA is the modeling of all inputs - the baseline, deployment scenario assumptions, benefits, and costs – to derive an estimated benefit, cost, and net benefit (benefits – costs). These are the expected nationwide values assuming the deployment scenario that will be realized by the applications. A transportation specific BCA tool is utilized to derive these values and outputs include year-by-year monetized benefits, costs, and net benefits. The cumulative value for each output is available as well. For monetary values, the results are discounted to provide the net present value of the total. The discount rate used in the analysis is seven percent pursuant to guidance by the Office of Management and Budget (OMB).[1] Both future benefits and costs are discounted by seven percent annually (see Footnote 2 on net present value and discount rate for additional information).

Organization of the Report

1. **Baseline:** Provides a description of the current impact of adverse weather.
2. **Deployment Scenario:** Provides a detailed description of the key CVE variables, the sources used to project the scenario characteristics, and assumptions related to adoption deployment.
3. **Safety Benefit Estimation:** A detailed description of the approach and sources used to evaluate each application's safety benefits.
4. **Non-Safety Benefit Estimation:** A detailed description of the approach and sources used to evaluate each application's non-safety benefits.
5. **Cost Estimation:** A detailed description of the approach and sources used to evaluate cost elements for the CVE core, road weather specific costs, and application specific costs.
6. **National Extrapolation:** A detailed description of the approach used to estimate the actual benefits, costs, and net benefits for the nation assuming the given deployment scenario.
7. **Limitations of the Analysis:** Provides major limitations.
8. **Results:** Provides results for each application, the total Program, and an application comparison.

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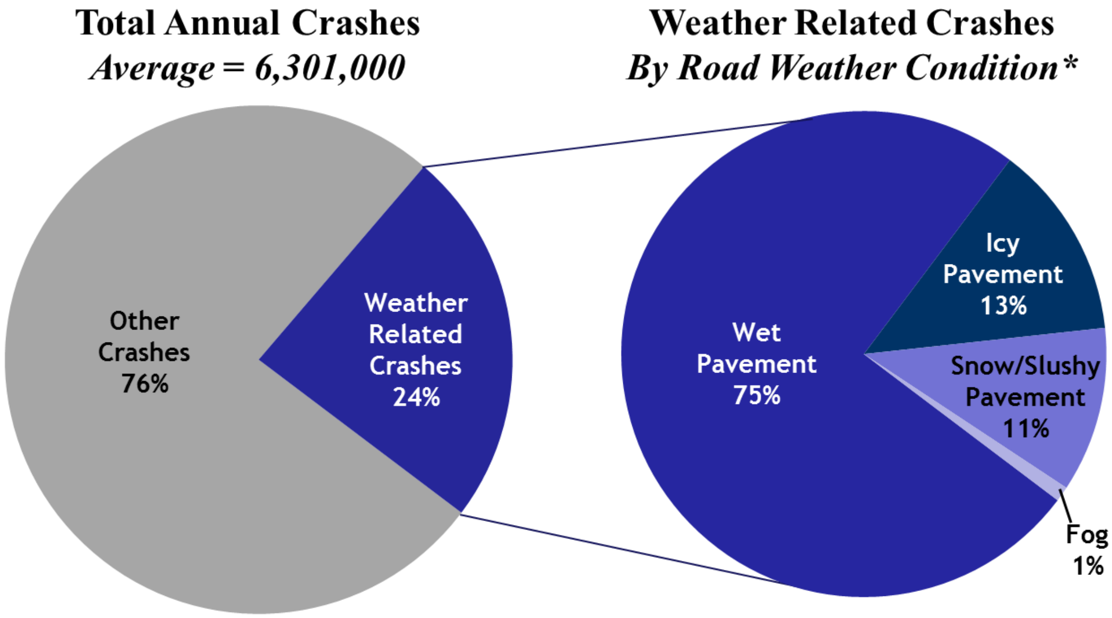
1. Office of Management and Budget. *Circular No. A-94 Revised*, Memorandum for Heads of Executive Departments and Establishments, Subject: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. Available at: http://www.whitehouse.gov/omb/circulars_a094#8.

2. When considering benefits and costs that will occur in the future, it is customary to discount those costs and benefits. The discount rate is the amount associated with the "real value" of money as well as the "time value of money". The "real value" is accounting for inflation that occurs over time. In addition, there is a "time value of money" which represents the time preference for money. For example, when most people are asked if they would rather have $90 today or $100 in one year, they would choose $90 today; that person is discounting the future value of money by 10%. This BCA utilized a 7 percent discount rate pursuant to guidance by OMB. Both future benefits and costs are discounted by 7 percent annually. To calculate the net present value over the entire period of analysis; this discount rate is utilized to derive the current value of the cumulative benefits and costs accrued over the life of the analysis.

Baseline: Current Impacts of Adverse Weather

Weather has a significant impact on the safety of the nation's roadway system. The direct results of weather include: rain causing wet, slick pavements; winter weather can leave pavements snow-covered or icy; and fog, blowing dust, heavy precipitation, and vehicle spray can restrict visibility. Weather related crashes constitute 24 percent of the crashes on roadways each year. These crashes have safety impacts including fatalities, injuries, and property damage. Weather has non-safety related impacts as well, including increases in travel time for motorists, reductions in freight operations and efficiency, and environmental impacts related to the treatment of roads. For the purpose of the current analysis, the safety impacts are the main focus. As illustrated by Figure 4, nearly one-quarter of all crashes occur under adverse weather conditions. The majority of weather related crashes (75%) occur under wet pavement conditions, an additional 13 percent occur with icy pavement, and 12 percent occur during snow/slushy pavement or foggy conditions.

Figure 4. Weather Related Crashes



*Crashes that occurred under adverse conditions; additional factors such as rain, snow, and fog are not disaggregated from pavement conditions in this graphic. The percentage due to fog is for those crashes that occur under foggy conditions, but not wet, icy, or snowy pavement conditions.

Source: Road Weather Management Program, Table: Weather-Related Crash Statistics (Annual Averages), *Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.*

The number of crashes that occur under adverse weather conditions is correlated with safety impacts. The number of crashes that occur under each type of read weather condition is well documented. The average annual number of crashes that occur in the United States under adverse weather is 1.5 million. As a result, approximately 629 thousand injuries and more than seven thousand fatalities occur.[3] Table 2 provides the detailed average annual number of crashes, injuries, and fatalities for each type of road weather condition. It should be noted that these values are not cumulative; for instance, a crash that occurs during rain will also occur under wet pavement conditions. These values provide the relative magnitude of weather conditions impacts on safety. Wet pavement and rain are responsible for the highest proportion of crashes, injuries, and fatalities.

Table 2. Number of Injuries and Fatalities that Occur as a Result of Weather Related Crashes

Road Weather Conditions	Crashes	Injuries	Fatalities
Wet Pavement	1,128,000	507,900	5,500
Rain	707,000	330,200	3,300
Snow /Sleet	225,000	70,900	870
Icy Pavement	190,100	62,700	680
Snowy/Slushy Pavement	168,300	47,700	620
Fog	38,000	15,600	600
Total Attributed to Weather*	1,511,200	629,300	7,130

* The sum of the crashes under each road weather condition does not equal the total number attributable to weather; crashes may be double counted, e.g. wet pavement and rain.

Source: Road Weather Management Program, Table: Weather-Related Crash Statistics (Annual Averages), *Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm, accessed January 11, 2013.*

Each year, crashes that occur under adverse weather conditions contribute to $70.7 billion in property damage (2012 USD).[4] This accounts for the damage caused by vehicles to the road itself, damage to other infrastructure such as telephone poles and bridges, and the cost related to vehicle damage incurred in the crash. The current number of crashes, fatalities, injuries, and property damage incurred under adverse weather conditions today represents the total possible safety benefits that could be reduced by road weather application deployment. The current statistics include the reductions already achieved by ITS road weather

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3. *Road Weather Management Program, Table: Weather-Related Crash Statistics (Annual Averages),* Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

4. Miller, Dr. Ted R. & Dr. Eduard Zaloshnja, A study by the Pacific Institute for Research & Evaluation Commissioned by The Transportation Construction Coalition. *On a Crash Course: The Dangers and Health Costs of Deficient Roadways*. May 2009.

management and increases in the safety of vehicle to date. This is the baseline upon which the applications will be compared.

Weather also has non-safety related impacts on the roadways including increases in travel time for motorists, reductions in freight operations and efficiency, and environmental impacts related to the treatment of roads. For the purpose of the current analysis, the non-safety impacts are the main focus. In addition to reducing mobility and having operational burdens on state and local agencies, adverse weather related congestion leads to wasted fuel, greenhouse gas emissions (GHG) and criteria pollutant emissions. GHG and criteria pollutant emissions have negative environmental and health effects. Below are brief descriptions of the direct and indirect impacts of each of these benefit categories.

Greenhouse Gas Impacts

Surface transportation (light duty vehicles, transit, and commercial freight) contributes 1.5 billion tons of carbon dioxide (CO_2) annually.[5] CO_2 emissions are a significant factor in global climate change. Increases in the atmospheric concentration of CO_2 are expected to lead to negative impacts including increases in droughts in some regions and heavy precipitation events in others, reduced water availability in regions supplied by meltwater, increased risk of coastal erosion and sea level rise, and increased disturbances from pests, diseases, and forest fire, among others.[6] CO_2 emissions have implications on a global scale and reducing the quantity of those emissions may help reduce the severity of the expected impacts.

GHGs are emitted during driving and while idling; they can be minimized by reducing idling time and by driving at optimal speeds. The applications can reduce the quantity of CO_2 emitted from vehicles by addressing incident related congestion and enhancing the infrastructure to optimize traffic throughput.

Criteria Pollutant Impacts

Unlike GHGs, criteria pollutants are regulated by the Clean Air Act under the authority of the EPA due to the risk that these pollutants can harm human health, in addition to having negative impacts on the environment and damaging property. These pollutants are called "criteria" air pollutants because they are regulated by the EPA based on human health and/or environmental criteria (science-based guidelines) for setting permissible levels. The four criteria pollutants considered in this analysis all have health and environmental impacts as described in more detail below.

Particulate Matter: There are a number of health impacts related to the ambient levels of particulate matter; most of which are experienced in the local or regional area. The impacts include increases in cardiovascular and respiratory-related mortality, increased visits to the hospital as a result of respiratory effects, and admissions related to chronic obstructive pulmonary disease (COPD), respiratory infections, and asthma; and exacerbation of respiratory symptoms in asthmatic children.[7]

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5. Department of Energy, Energy Information Administration. *Annual Energy Outlook 2011 Transportation Sector Statistics*. May 2011.

6. Intergovernmental Panel on Climate Change. *IPCC Fourth Assessment Report: Climate Change 2007*. Available at: http://www.ipcc.ch/publications_and_data/ar4/wg2/en/spmsspm-c-12-north-america.html.

7. Environmental Protection Agency. *Regulatory Impact Analysis: Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.* 2010.

Hydrocarbon: Hydrocarbon emissions are a precursor to ground level ozone which has detrimental impacts on health including difficulty breathing, lung damage, and reduced cardiovascular functioning. A number of hydrocarbons are also considered toxic and can cause cancer or other health problems. Ground level ozone also reduces visibility and causes other environmental damage.[8]

Carbon Monoxide: Carbon monoxide has significant human health impacts. Exposure to increased ambient levels has been associated with increased cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease. Exposure can also result in neurological damage, pulmonary function damage, and mortality.[9]

Oxides of Nitrogen: Oxides of nitrogen have both human health implications as well as environmental impacts. Oxides of nitrogen have been found to increase sensitivity in asthmatics and cause other lung-related effects. Nitrogen emissions can leave the local area and be deposited in distant areas; excess deposition can lead to acidification and nutrient enrichment (leading to harmful algal blooms) in aquatic ecosystems.[10]

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8. Environmental Protection Agency, Office of Transportation and Air Quality. *Mobile Source Emissions: Past, Present, and Future, 2012.* Available at: http://opusinspection.com/documents/def_pollution.htm.

9. Environmental Protection Agency. *Regulatory Impact Analysis: Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.* 2010.

10. Ibid.

Deployment Scenario

The road weather applications will leverage an imagined CVE and road weather specific technology to collect, disseminate, process, and utilize more accurate road weather data and in so doing reduce travel delays, decrease environmental impacts, and reduce winter maintenance operational costs that occur under or due to adverse weather conditions. To estimate the impact of these applications, it is necessary to first assess the level of deployment of the CVE core, the road weather specific technology, the application adoption rate, and the application maturity effectiveness factor.

CVE Core Deployment

The core connected vehicle environment will require the deployment of several types of equipment to wirelessly connect vehicle-to-vehicle (V-V) and vehicle-infrastructure (V-I). Vehicles will have on-board equipment (OBE) units which broadcast and capture dedicated short-range communication (DSRC) from other vehicles and from the infrastructure. The OBE may also act as the display screen for messages and/or warnings (e.g., slippery road 20 feet ahead). To collect and collate information from multiple vehicles in an area, roadside equipment (RSE) is expected to be required to receive and broadcast DSRC between vehicles and TMCs. RSEs can be located along the road for a given road segment or at signalized intersections for intersection operations. OBEs and RSEs are not currently commercially developed or deployed; therefore to assess the coverage of a connected vehicle system, the deployment scenario must assume a set of projections for the deployment of these technologies.

On-Board Equipment Deployment Rate

To estimate the deployment of OBE, projections from the Department of Transportation Volpe Transportation Research Center (Center) were used for the purpose of BCA. The assumptions are that only new vehicles will have an OBE and implementation will begin in 2017 with a 3-year phase-in period for all vehicle types.[11] The start of implementation is based on a 2013 National Highway Traffic Safety Administration (NHTSA) decision, 2 years for rule-making, and 2 years for litigation prior to manufacturers beginning to incorporate the equipment. These assumptions were used in the current BCA for light duty passenger vehicles and light duty trucks and heavy trucks (delayed by 1 year with the NHTSA decision for trucks expected in 2014) pursuant to NHTSA's authority to regulate those vehicles for safety. It was determined that transit vehicles, however, would not be required to comply with the same obligatory regulation. To project the deployment of OBE in transit vehicles, therefore, the deployment schedule for fixed route buses to adopt automatic vehicle location (AVL) technology—a comparable, voluntary implementation of an intelligent transportation system—was used as an analog. The deployment schedule for AVL took 10 years and only reached 68 percent;[12] it is assumed in this

11. Department of Transportation John A. Volpe National Transportation Systems Center. *AERIS Evaluation: Assumptions on Baselines, Connected Vehicle Deployment & Sensitivity Testing;* Internal Draft. January 25, 2012

12. Department of Transportation, Research and Innovative Technology Administration, Intelligent Transportation Systems. *Transit Management Deployment Statistics*. April 2011. Available at: http://www.itsdeployment.its.dot.gov/TM.aspx.

BCA that transit vehicles will begin deployment in 2018 (similar to heavy trucks) and over 10 years will reach an installation rate of 68 percent in new transit vehicles.

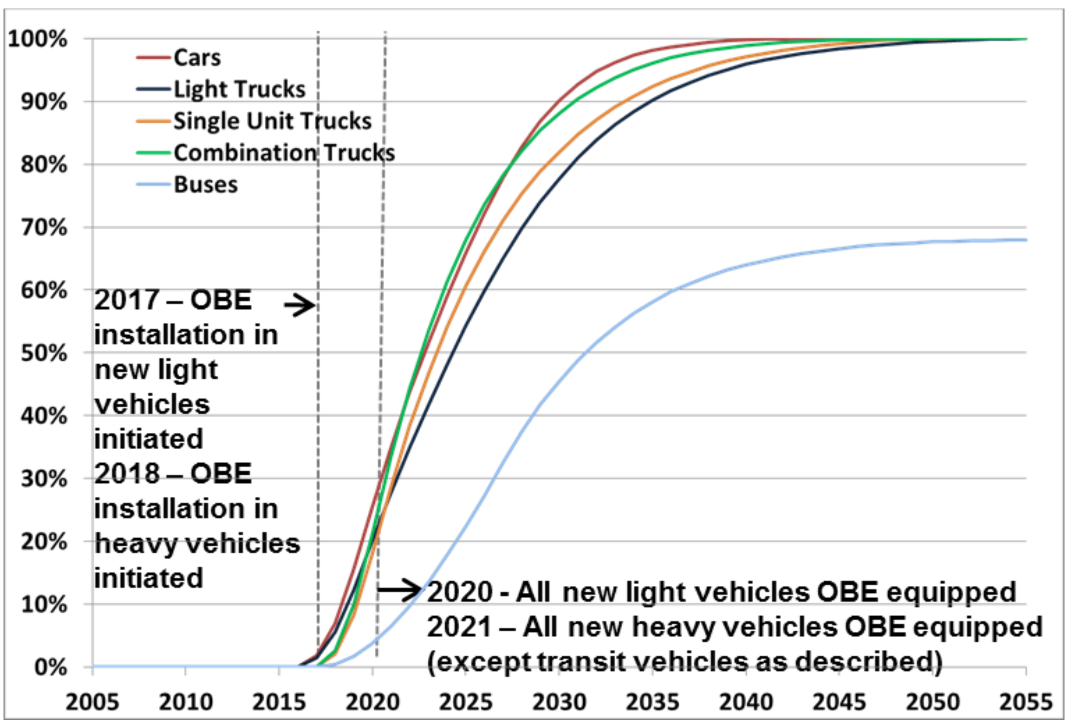
The deployment schedules for all vehicle types were integrated into a fleet turnover model based on data provided by FHWA[13] to estimate the number and type of vehicles that would have an OBE for each year through 2055. Table 3 provides the deployment rate assumptions utilized in the analysis. Figure 5 shows the calculated percentage of the on-road vehicles by type that have an OBE installed. Note the OBE assumptions are the same as those utilized in the AERIS Program BCA of connected vehicle applications for the environment.

Table 3. OBE Deployment Rate Assumptions

Vehicle Class	Phase-In Start	Phase-In Duration	Installed at Maturity
Cars	2017	3	100%
Light Trucks	2017	3	100%
Single Unit Trucks	2018	3	100%
Combination Trucks	2018	3	100%
Buses	2018	10	68%

Source: Booz Allen Hamilton, January 2013.

Figure 5. On-Road Vehicles with OBE



Source: Booz Allen Hamilton, January 2013.

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13. Department of Transportation, Federal Highway Administration. *Fleet Turnover Model*. 2011.

Roadside Equipment Deployment Rate

The Volpe Center estimated the deployment rate of RSEs as well; this was used as the basis in the current BCA for RSE deployment. Installation begins in 2015 and takes 5 years. A total of 252,000 RSEs would be in place at the end of this installation period. This includes 25,000 RSEs on urban freeways (a spacing of approximately one per road mile), 17,000 RSEs on rural freeways (a spacing of approximately one for every two road miles), and 210,000 RSEs at urban traffic lights (this is approximately two-thirds of all urban signals estimated to provide complete metropolitan area coverage).[14] The Volpe Center also estimated the number of each of the three types of RSEs that would be connected by wireline (for power) or be wireless; these assumptions will be described as they relate to costs in the cost estimation section. While the Volpe Center projects initial installation, there are no estimates for the installation of RSEs after five years as roads are reconstructed, new roads are constructed, and/or new signalized intersections are built.

Road miles increase by 0.1 percent annually[15]; the current BCA assumes that RSEs grow at the same spacing assumption as the initial installation period in proportion to road mile growth. New signals are installed at a rate in proportion to population growth; the average number of signals in a given area is one per 1,000 people, this is used to estimate the number of new signals with RSEs after the initial installation period. Deployment assumptions are displayed in Table 4. Figure 6 shows RSEs deployed by type.

Table 4. RSE Deployment Rate Assumptions

RSE Type	Phase-In Start	Phase-In Duration	Installed at Maturity
Urban Freeway	2015	5	1 per 1 mile
Rural Freeway	2015	5	1 per 2 miles
Urban Signal	2015	5	2/3 of signals

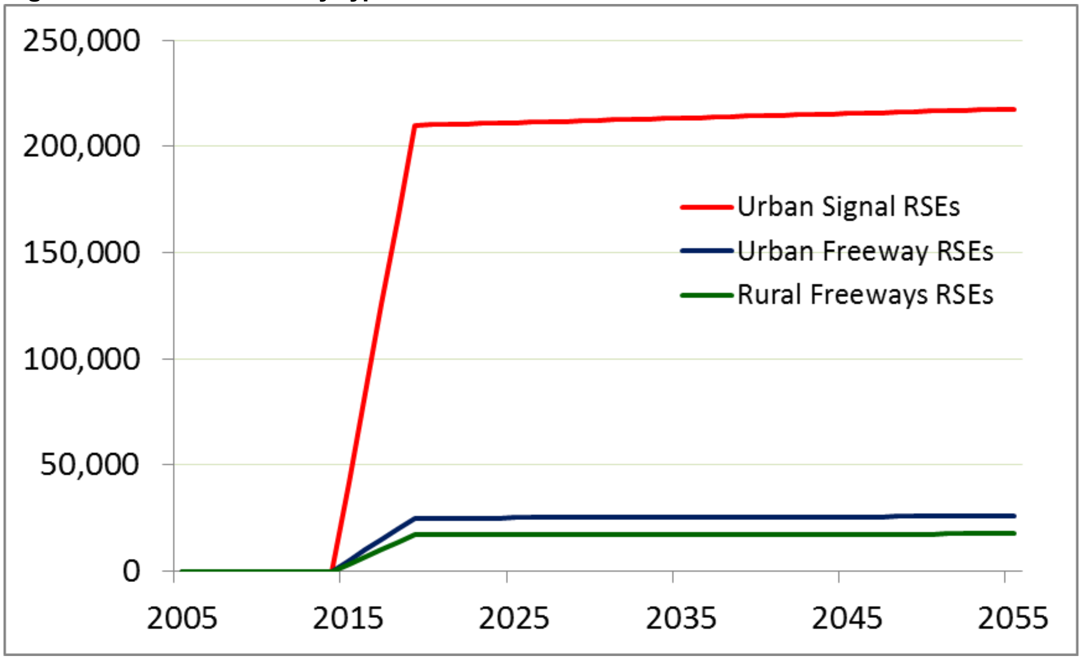
Source: Booz Allen Hamilton, January 2013.

It is worthwhile to note that this assumption departs from that utilized for the AERIS BCA; the AERIS BCA assumed that core infrastructure would be in-place rather than the program installing required equipment. Based on this important assumption, the AERIS BCA utilized a conservative estimate of RSEs that would be installed on the road or at signalized intersections that are trouble spots. The AERIS BCA therefore, assumes the spacing for RSEs on freeways will be phased in over 25 years and at a spacing of 10 miles. Signal RSEs will also be phased in over 25 years and only be installed at one third of signals. A significant distinction between the AERIS applications and the Road Weather Management applications being considered in this report is that many of the AERIS applications do not rely on RSEs based on the lower dependence on latency; these applications can largely utilize cellular communications. Road weather management applications, however, require much higher latency to ensure safety and therefore require DSRC based RSEs. With this in mind, the current RSE deployment assumption is based on Volpe's estimates to provide full coverage.

14. Department of Transportation John A. Volpe National Transportation Systems Center. *AERIS Evaluation: Assumptions on Baselines, Connected Vehicle Deployment & Sensitivity Testing;* Internal Draft. January 25, 2012.

15. Department of Transportation John A. Volpe National Transportation Systems Center. Personal Communication. March 2012.

Figure 6. RSEs Installed by Type



Source: Booz Allen Hamilton, January 2013.

Road Weather Specific Technology Deployment

Road weather applications will not only leverage the CVE core, there is an additional technology being developed that they will utilize called the Vehicle Data Translator (VDT). This technology will be an aggregator of data, retained at TMCs and used to process atmospheric and pavement data and support the road weather applications. As a relatively low cost technology, it is assumed that VDT deployment will not be a limiting factor in the scenario. Therefore, an analytical assumption is that if the CVE core and application are deployed that the VDT is available.

Application Deployment

The individual applications will also have a deployment rate. Information is not available in the literature or from an authoritative source on the likely deployment schedule of the applications, therefore a conservative deployment schedule was developed (similar to other connected vehicle application deployment rates in recent literature).[16] Due to high uncertainty in the deployment rate for any of the applications, the same deployment schedule was assumed for all applications. The applications are deployed in three distinct phases: a short, medium, and long term.

The short term is defined to be from 2015 through 2022, the medium term is from 2023 to 2032, and the long term is from 2032 and beyond. By the end of the short term, applications will be adopted at a rate of 15

16.Department of Transportation ITS JPO. *AERIS Applications for the Environment: Real-Time Information Synthesis Identification and Evaluation of Transformative Environmental Applications and Strategies Project, Initial Benefit-Cost Analysis*; August 2012.

percent. By the end of the medium term, deployment reaches 50 percent. For the long term, 75 percent deployment is achieved by 2045 and remains at this level through the end of the period of analysis. Table 5 shows the assumptions used to estimate application deployment. *Source: Booz Allen Hamilton, January 2013.* Figure 7 projects implementation levels for all applications.

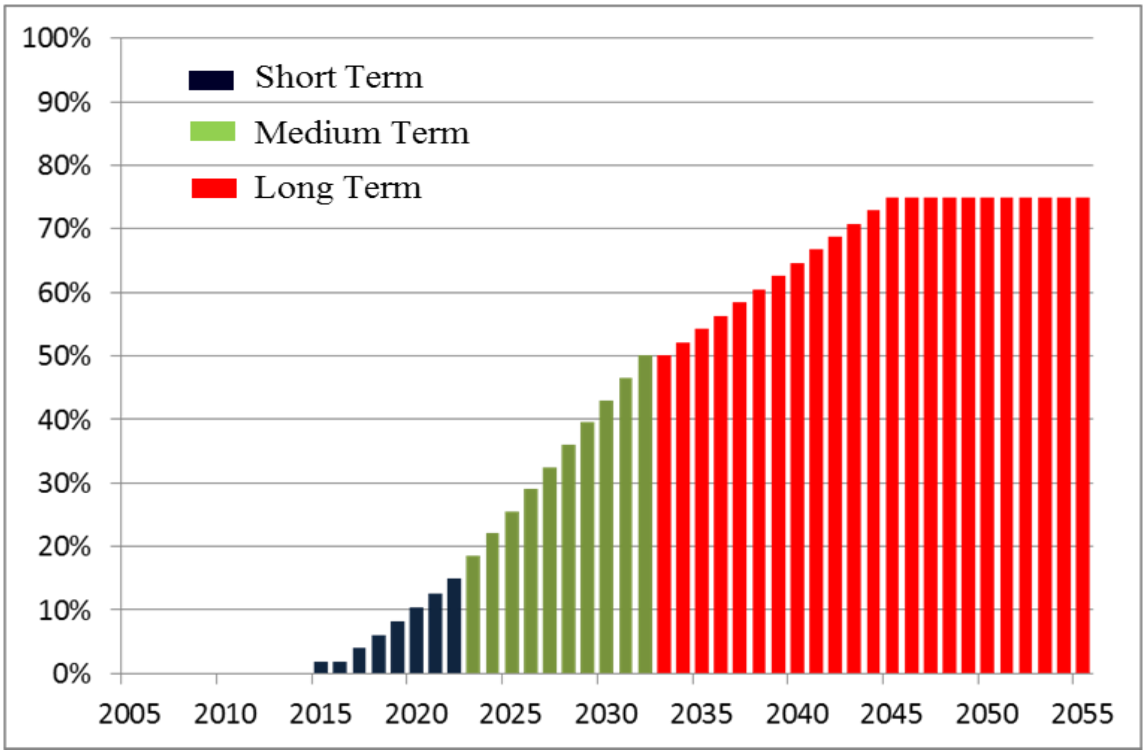
Table 5. Application Deployment Rate Assumptions

	Short	Medium	Long
All Applications	15%	50%	75%

Short Term = 2015 – 2022
Medium Term = 2023 – 2032
Long Term = 2033 – 2055

Source: Booz Allen Hamilton, January 2013.

Figure 7. Application Deployment Profile (Percent)



Source: Booz Allen Hamilton, January 2013.

Application Maturity Effectiveness Factor

The confidence/performance of the applications relies on a minimum amount of "connectivity"; to account for this, a maturity factor reduces benefits in the initial stages when deployment of OBEs is low. The specific assumption is: if OBE deployment is less than 30 percent, application performance equals 50 percent; if OBE deployment is 30 – 50 percent, application performance equals 75 percent; and if OBE deployment is greater than 50 percent, application performance is 100 percent.

Safety Benefit Estimation

Weather affects roadway safety by increasing exposure to hazards and crash risk. Weather also impacts the operational effectiveness and productivity of traffic management agencies and road maintenance agencies through increased costs and lost time. Accurate, timely, route-specific weather information, allows traffic and maintenance managers to better operate and maintain roads under adverse conditions and can be leverage by drivers to practice safer driving strategies.

Connected vehicle road-weather applications efficacy is as good (although potentially better) than conventional ITS road-weather technologies. The major factor in increasing safety is the deployment of connected vehicle technologies. If conventional ITS was deployed everywhere, it could potentially yield high safety benefits; however, it is cost prohibitive. Connected vehicle road-weather applications utilize a mobile fleet of pavement and atmospheric sensors, leveraging the CVE core to provide national coverage.

Benefit Estimation Overview

There are three main components to benefit evaluation when looking at the safety impacts of the road weather applications: efficacy, incidence, and monetization. The efficacy of the application is the potential reduction it may provide in crashes, fatalities, injuries, and property damage. For instance, an application that provides a motorist with a warning to slow down may reduce 20 percent of crashes; that is the efficacy of the application. Efficacy of applications is based on literature review of conventional ITS and expected connected vehicle safety benefits for the purposes of this analysis.

The second factor is the incidence; this is an evaluation of how often the given application may actually be applicable. It should be noted that this is the total potential incidence. The incidence will get further reduced based on deployment of the CVE core and the applications. An example of incidence is that the motorist advisory may provide appropriate information during the 707,000 crashes that occur under rain conditions. Incidence estimates are predominantly based on information from the NHTSA Fatality Analysis Reporting System (FARS).[17] Efficacy and incidence are utilized in the analysis to estimate the potential number of crashes, fatalities, injuries, and property damage that may be avoided due to the application as illustrated:

$$\textit{Efficacy} \times \textit{Incidence} = \textit{Safety Benefits}$$

Monetization

While these values are important (e.g., number of lives saved), for a BCA, it is necessary to monetize the qualitative safety benefits so that the benefits and costs may be compared. For the purpose of this analysis, property damage is already estimated in monetary terms. The number of fatalities and injuries avoided can be estimated using standard values. The sum of property damage, fatalities, and injuries avoided comprises the value of crashes avoided.

17.Department of Transportation National Highway Traffic Safety Administration. *NCSA Data Resource Website Fatality Analysis Reporting System (FARS) Encyclopedia*. Available at: http://www-fars.nhtsa.dot.gov/Main/index.aspx.

The monetary value of a fatality avoided has been estimated by the Department of Transportation. The current value, value of a statistical life, is $6,204,743 (2012 USD) in 2012 and the value increases by 0.0877 percent per year.[18] The BCA utilizes both the current value for 2012 and the increasing value over time through 2055. These values are the pre-discounted value, in other words, when summing the entire period, the values are discounted by seven percent each year based on the value of a future live saved.

The Department of Transportation also has a standard value for injuries avoided. There are six severity levels with associated values estimated by the Department. Due to a lack of information on the severity of injuries incurred under adverse weather, the BCA utilized an average value of the injury severity levels; therefore assuming that on a national basis, the severity of injuries due to adverse weather is equally distributed. The injury value used for the analysis is $1,258,322 (2012 USD) in 2012 and increases by 0.0877 percent per year.[19]

To estimate the value of property damage avoided, the analysis assumes that the proportion of property damage that is attributable to inclement weather is the same as the proportion of crashes due to inclement weather; therefore 24 percent of property damage is due to inclement weather.[20] The annual property damage in the United States of infrastructure and vehicles is $70.7 billion (2006 USD)[21]; 24 percent of this value is computed to be $19.3 billion (2012 USD – converted from 2006 using Bureau of Labor Statistics inflation factors[22]). This value is held constant over time in the analysis.

Application Specific Benefit Estimation

Enhanced Maintenance Decision Support System – The efficacy of this application to reduce crashes is estimated at 0.07 percent based on the average of Minnesota and Colorado case studies evaluating enhanced maintenance decision support systems conducted in 2009.[23] To estimate the incidence, FARS data is utilized.[24] This application is applicable to crashes that occur in winter months (Nov, Dec, Jan, Feb, and March) based on the case studies. Using FARS data, the total U.S. fatalities that occur in those months is 12,121.

To estimate the number of crashes, the analysis uses a factor of 212 crashes to 1 fatality (based on weather related statistics of 7,130 fatalities to 1,511,200 crashes) and to estimate injuries uses a factor of 88 injuries to 1 fatality (based on weather related statistics of 629,300 persons injured to 1,511,200 crashes).[25] Total annual U.S. property damage incurred under adverse conditions is $19.3 billion is adjusted for winter only (5/12 months) equals $8 billion.

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18. Department of Transportation National Highway Traffic Safety Administration. *NHTSA Revised Departmental Guidance: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses - 2011 Revision.*

19. Ibid.

20. Road Weather Management Program, *Table: Weather-Related Crash Statistics (Annual Averages)*, Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

21. Miller, Dr. Ted R. & Dr. Eduard Zaloshnja, A study by the Pacific Institute for Research & Evaluation Commissioned by The Transportation Construction Coalition. *On a Crash Course: The Dangers and Health Costs of Deficient Roadways.* May 2009.

22. Bureau of Labor Statistics. *BLS Inflation Calculator Tool*; Available at: http://www.bls.gov/data/inflation_calculator.htm.

23. Western Transportation Institute. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs.* May 2009.

24. Department of Transportation National Highway Traffic Safety Administration. *NCSA Data Resource Website Fatality Analysis Reporting System (FARS) Encyclopedia*. Available at: http://www-fars.nhtsa.dot.gov/Main/index.aspx.

25. Road Weather Management Program, *Table: Weather-Related Crash Statistics (Annual Averages)*, Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

The efficacy (0.07 percent) is multiplied by the incidence and yields a potential annual nationwide reduction of 1,820 crashes, 9 fatalities, 758 injuries, and $6 million. As previously mentioned these values will be reduced based on estimated deployment. The benefits are held constant for the life of the analysis. The monetary value for fatalities and injuries, however, varies by year and is incorporated along with the deployment scenario in the extrapolation of the application.

Information for Maintenance and Fleet Management Systems – Based on available literature, there are no safety benefits for this application; the purpose of information for maintenance and fleet management systems is to provide cost savings in their treatment strategies which will be evaluated in Phase II. This application may work in concert with the Enhanced Maintenance Decision Support System; however, the safety benefits are already captured in the analysis of that application.

Variable Speed Limits for Weather-Responsive Traffic Management – This application is evaluated as two sub-applications, variable speed limits in work zones, and non-work zones. The efficacy is two percent in summer and 13 percent in winter based on a study that evaluated the effectiveness of variable speed limits on behavior.[26] The incidence is based on FARS data in summer, which reports that there are 70 fatalities in work zones and injuries and crashes are estimated using previously described factors. In summer, in non-work zones, FARS reports 3,460 fatalities. In winter, fatalities in work zones are reported at 28; in winter, in non-work zones there are 2,033 fatalities.

The efficacy (2 percent in summer and 13 percent in winter) is multiplied by the incidence and yields a potential annual nationwide reduction in crashes in work zones of 1,311, 5 fatalities, and 544 injuries. Property damage is estimated in the non-work zone sub application only. For non-work zones, the potential annual nationwide reduction in crashes is 18,130, 333 fatalities, 36,250 injuries, and $1.6 billion in property damage avoided. As previously mentioned these values will be reduced based on estimated deployment. The benefits are held constant for the life of the analysis. The monetary value for fatalities and injuries, however, varies by year and is incorporated along with the deployment scenario in the extrapolation of the application.

Motorist Advisories and Warnings – The efficacy of this application is 20 percent based on a study conducted in Finland on the behavioral impacts of drivers to weather alerts and the associated safety benefits.[27] Incidence is estimated as the total annual fatalities that occur in inclement weather – according to FARS there are 32,885[28] annual fatalities and multiplying by 17%[29] for incidence under inclement weather yields 5,590 fatalities (in 2011). Crashes and injures are estimated using the previously described factors.

The efficacy (20 percent) is multiplied by the incidence and yields a potential annual nationwide reduction in crashes of 237,035, 1,118 fatalities, 98,392 injuries, and $3.8 billion. As previously mentioned these values will be reduced based on estimated deployment. The benefits are held constant for the life of the analysis. The monetary value for fatalities and injuries, however, varies by year and is incorporated along with the

26. Rämä, Pirkko, Senior research scientist and Anna Schirokoff, Research scientist; VTT Technical Research Centre of Finland. *Effects of Weather-Controlled Variable Speed Limits on Injury Accidents.*

27. Kumala, Rämä. *The Effects of Weather and Road Condition Warnings on Driver Behaviour.* 2nd World Congress on Intelligent Transport Systems, Technical Research Centre of Finland (VTT).1995

28. Department of Transportation National Highway Traffic Safety Administration. *NCSA Data Resource Website Fatality Analysis Reporting System (FARS) Encyclopedia*. Available at: http://www-fars.nhtsa.dot.gov/Main/index.aspx.

29. Road Weather Management Program, *Table: Weather-Related Crash Statistics (Annual Averages)*, Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

deployment scenario in the extrapolation of the application. This application has a high efficacy and relatively high impact due to the application to most crashes that occur under adverse weather.

Information for Freight Carriers – This application is expected to have the same efficacy as motorist advisories and warnings application, while having a lower incidence as it is only applicable to freight vehicles. Incidence is based on FARS data for vehicle types including: cargo tank, flatbed, dump, concrete mixer, garbage/refuse, grain/chips/gravel, pole-trailer, log, and intermodal container chassis. FARS reports that there are 451 fatalities for these vehicles, which is multiplied by 17 percent to account for inclement weather. Crashes, injuries, and property damage are calculated using the previously described approach.

The efficacy (20 percent) is multiplied by incidence and yields a potential annual nationwide reduction in crashes of 3,251, 15 fatalities, and 1,349 injuries. The previous application already accounts for total national property damage avoided so it is not included in this application's evaluation. As previously mentioned these values will be reduced based on estimated deployment. The benefits are held constant for the life of the analysis. The monetary value for fatalities and injuries, however, varies by year and is incorporated along with the deployment scenario in the extrapolation of the application.

Information and Routing Support for Emergency Responders – This application's efficacy is expected to be the same as the previous two applications (20 percent). Incidence is estimated based on information about the number of accidents that occur annually in ambulances.[30] The efficacy is multiplied by the incidence and yields a potential annual nationwide reduction in crashes of 20, 1 fatality, and 4 injuries.

Weather-Responsive Signal Timing – There is limited data on the efficacy of weather-responsive signal timing. The analysis assumes that the application's efficacy will be consistent with motorist advisories and other applications. Incidence is based on an estimate that six percent of all crashes occur in signalized intersections.[31] The benefits are therefore estimated to be six percent of all benefits of motorist advisory which yields a reduction of 14,222 crashes, 67 fatalities, 5,903 injuries, and $232 million avoided in property damage. As previously mentioned these values will be reduced based on estimated deployment. The benefits are held constant for the life of the analysis. The monetary value for fatalities and injuries, however, varies by year and is incorporated along with the deployment scenario in the extrapolation of the application.

30. http://www.emsworld.com/article/10225399/ambulance-crash-roundup

31. http://safety.transportation.org/htmlguides/sgn_int/exec_sum.htm

Non-Safety Benefit Estimation

In addition to safety related impacts associated with weather conditions, weather also impacts the mobility of drivers, the environment, and the operational effectiveness and productivity of traffic management agencies and road maintenance agencies. Accurate, timely, route-specific weather information, allows traffic and maintenance managers to better operate and maintain roads under adverse conditions and can be leveraged by drivers to practice safer, more informed driving strategies. This section describes the non-safety benefits of the road weather connected vehicle applications – specifically the mobility, environmental, and operational cost savings.

Benefit Estimation Overview

The non-safety benefit categories considered in this BCA are mobility, environmental, and operational cost savings. Table 6 below provides the detailed benefits within each of the categories and the unit by which each is measured.

Table 6. Non-safety Benefit Categories

Benefit Category	Benefit	Unit of Measurement
Mobility Benefits	Passenger Vehicle Travel Time Savings	Hours
	Freight Vehicle Travel Time Savings	Hours
	Fuel Savings	Gallons
Environmental Benefits	GHG Emissions	Grams
	Particulate Matter	Grams
	Hydrocarbons	Grams
	Carbon Monoxide	Grams
	Nitrous Oxide	Grams
	Salt (environmental impacts)	Millions of Tons
Operational Cost Savings	Labor Savings	Millions 2012 USD
	Salt (material costs)	Millions of Tons

Source: Booz Allen Hamilton, January 2013.

Each of these benefits is evaluated utilizing three main components: efficacy, incidence, and monetization. The efficacy of the application is the potential to provide the benefit; for instance, an application may reduce travel time by 20 percent, which is the efficacy of the application. Efficacy of applications is based on literature review of conventional ITS and expected connected vehicle non-safety benefits for the purposes of this analysis.

The second factor is the incidence; this is an evaluation of how often the given application may actually be applicable. It should be noted that this is the total potential incidence. The incidence will get further reduced based on deployment of the CVE core and the applications. An example of incidence is that an application may provide appropriate information during the 707,000 crashes that occur under rain conditions, reducing incidence, thus reducing incident related congestion. Incidence estimates are predominantly based on literature review of conventional ITS and expected connected vehicle non-safety benefits for the purposes of this analysis. Efficacy and incidence are utilized in the analysis to estimate the potential number of non-safety benefits that may be generated due to the application as illustrated:

$$Efficacy \times Incidence = Non\text{-}safety\ Benefits$$

Monetization

While the qualitative non-safety values are important (e.g., hours of travel time saved), for a BCA, it is necessary to monetize the qualitative non-safety benefits so that the benefits and costs may be compared.

Mobility Benefits Monetization - The value of travel time saved (VTTS) for passenger vehicle occupants is based on the opportunity cost of travel. For each occupant spending time travelling, there is an opportunity cost; they could be engaged in productive activities (earning wages) or engaged in recreation (for which they are willing to pay). Additionally, travel during part or all of the trip may be unpleasant and involve tension, fatigue, or discomfort. These three factors are considered in the estimation of VTTS. The Department of Transportation (DOT) provides guidance on a standard VTTS estimate for passenger vehicle occupants to ensure consistency in BCAs[32].

The DOT estimates the VTTS at $12.50 per person hour saved for 2011 (2009 USD). For the purposes of this analysis, the 2009 USD was converted to 2012 USD utilizing the Bureau of Labor Statistics (BLS) inflation calculator. The DOT guidance also directs one to escalate the VTTS on an annual basis by 1.6 percent. Utilizing this information, the BCA 2012 VTTS is $13.63 and this value increases by 1.6 percent annually through 2055.

Unlike VTTS for passenger vehicles, the value of freight time savings (VFTTS) incorporates factors such as the paid wage of the driver, the value of the freight being transported, the cost that is incurred if the shipment is delayed, and the maintenance and operations costs associated with the freight vehicle. THE DOT acknowledges that the VFTTS is an important consideration in a BCA; however, they do not provide standard guidance on what the cost should be. There have been several previous attempts at estimating an average value and this BCA utilizes an estimate that is based on a meta-analysis of five U.S. studies[33]. The VFTTS was estimated $20.25 (2002 USD) per shipment. For the purpose of this analysis, the VFTTS was escalated to 2012 USD to $25.93 and is escalated by 1.6 percent each year of the analysis through 2055 assuming that the VFTTS will increase at the same pace as the VTTS.

In addition to the value of passenger vehicle occupants and freight vehicle time, there is another benefit closely associated with mobility, fuel savings. Reduced speeds and especially congestion lead to wasted fuel. This analysis incorporates the fuel savings provided by increased mobility as a result of the applications into the benefit estimate. The Department of Energy, Energy Information Administration projects the price of fuel (motor gasoline) through 2035 in their Annual Energy Outlook (AEO). The AEO is updated each year and the most

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32. Department of Transportation. *The Value of Travel Time Savings - DOT guidance*; available at: http://www.dot.gov/sites/dot.dev/files/docs/vot_guidance_092811c.pdf.

33. Luca Zamparini & Aura Reggiani. *Freight Transport and the Value of Travel Time Savings: A Meta-analysis of Empirical Studies*, Transport Reviews: A Transnational Transdisciplinary Journal. 27:5, 621-636. 2007.

recent data, the AEO 2011, was utilized for the purposes of this analysis[34]. The AEO has several cases such as a high oil price case, a low oil price case, and other economic scenarios. This BCA uses the Reference Case which is the standard case projected by the AEO. AEO only provides a projection through 2035, so to estimate the fuel price from 2035 through 2055, the five-year average trend (2030-2035) was used to extrapolate the price through 2055. Based on the AEO and extrapolation, the fuel price increases annually at a rate of less than 1 percent, reaching $4.25 in 2055. The fuel price projected takes into account supply and demand and accounts for increasing supplies including biofuels and coal-to-liquids and reductions in demand caused by more efficient vehicles and the increase in hybrid and battery-powered vehicles.

Environmental Benefits Monetization - To improve consistency in evaluating the cost of GHGs, in 2009, an Interagency Working Group was convened to develop the standardized values for the "social cost of carbon." This group consisted of members from six federal agencies and White House offices. The projected social cost of carbon was estimated for the use of all government regulatory impact analyses. The monetary value of GHG was estimated for the period through 2050, and this analysis extended the value to 2055 using the trend from the previous 5 years[35]. In 2012, the GHG value is estimated at $70.35 per ton and this increases each year based on the projected value.

To estimate the monetary value of reducing criteria pollutant emissions, the EPA's published valuation projections were utilized. EPA's approach to estimating the value of reducing criteria pollutants is based on people's Willingness-to-Pay to improve their health and Willingness-to-Accept (compensation required to accept a deteriorated state of health), otherwise known as contingent valuation. Contingent valuation is a standard economic approach to monetizing non-market goods. EPA has assessed the value of criteria pollutants based on scientific evidence of the risks related to mortality, morbidity, and the costs associated with healthcare and loss of productivity due to exposure to these pollutants[36]. Based on this information, the monetary value of particulate matter is 229,200 per ton, hydrocarbons is 8,271 per ton, carbon monoxide is 1,439 per ton, and nitrous oxide is 4,160 per ton in 2012 (2012 USD)[37]. These values increase each year in the analysis based on the EPA projections.

The use of salt to treat roads has negative impacts on the road infrastructure, fresh water resources, local plant life and wildlife. These impacts are challenging to estimate and will vary greatly from one location to the next. However, there have been several attempts at monetizing the average impacts of road salt use. The Western Transportation Institute estimated that the hidden costs (in addition to the material costs) of salt use are $469 per ton[38]. This BCA used this value and held it constant for the entire period of analysis.

Operational Cost Savings Monetization - The two significant operational savings categories in this BCA are labor savings and salt material savings. The labor savings estimated in the BCA were derived directly from the case studies and extrapolated to the United States. There were no additional assumptions about labor rates. The savings provided by reducing the amount of salt use (while preserving level of service) is quantified by

34. Department of Energy, Energy Information Administration. *Annual Energy Outlook 2011, Reference Case*. May 2011.

35. Department of Transportation, National Highway Transportation Safety Administration. *Preliminary Regulatory Impact Analysis, Corporate Average Fuel Economy for MY 2017-MY 2025 Passenger Cars and Light Trucks.* November 2011.

36. Environmental Protection Agency. *The Benefits of the Clean Air Act, 1990 to 2010, Appendix H: Valuation of Human Health and Welfare Effects of Criteria Pollutants.* 2011.

37. Environmental Protection Agency. *Regulatory Impact Analysis: Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.* 2010.

38. Mackinac Center for Public Policy. *Michigan Road Salt: What is it Costing Us?.* 2011. Available at: http://www.michiganscience.org/article.aspx?ID=15189&print=yes.

utilizing the market derived price of salt in 2012. An evaluation of the price paid and five year average use of salt was undertaken to estimate the weighted average cost of salt in 2012 based on data from the Washington State Department of Transportation; the resulting cost is $59.38 per ton [39].

Application Specific Benefit Estimation

Enhanced Maintenance Decision Support System – This application provides data to road managers that can optimize the treatment of roads based on the additional information. Anticipated benefits are categorized as operational cost savings including labor savings and savings from reduced salt use. Additionally, reduced salt use will lead to less negative environmental impacts associated with salt treatment. To estimate the labor savings provided by this application, a study by the DOT ITS Program on the pre - and post-implementation of an Maintenance Decision Support System in Denver, Colorado was utilized. The results are documented in the report entitled "Benefit-Cost Assessment of a MDSS Implementation: the City and County of Denver"[40]. The report estimated that the average labor savings from the application are $95,359 per year.

The Denver estimate was then extrapolated to the United States by assuming that the share of labor savings to total expenditure on snow and ice removal would be the same in Denver as in the rest of th e country. Based on this logic the ratio of Denver expenditure to total U.S. expenditure was used to estimate total U.S. labor savings. The value for the annual U.S. expenditure on snow and ice removal (state and local expenditures) is $3,090,000,000[41]. The Denver area expenditure is $5,500,000; a ratio of 562 to 1. Therefore, the Denver labor savings were estimated at $53,574,139. Note that this is the total potential labor savings if the application was deployed 100% of the time and will be reduced based on estimated deployment.

The Enhanced Maintenance Decision Support System will also save salt used to attain the same level of service based on the additional information. To estimate the tons of salt saved by this application, a case study conducted in New Hampshire on the reduction of salt use based on the deployment of statewide MDSS was utilized. The study, "Benefit–Cost Analysis of Maintenance Decision Support System" estimated that in New Hampshire, maintaining the same level of service, MDSS would yield savings of 23,644 tons of salt per year[42]. According to the Washington State DOT, New Hampshire's fiver-year average salt use is 200,000 tons per year[43]. Based on the case study and average use, the application has an efficacy of 12 percent. The incidence (opportunity for salt savings) is based on the total salt used for the entire U.S. which is 12,953,675 tons according to the Washington State DOT. By applying the application efficacy to the incidence, the result is 1,531,383 tons of salt per year. This is the total potential salt savings and will be reduced based on the deployment schedule. Both the value of the material and the value associated with environmental impacts of salt will be used to determine the monetary value of the salt avoided.

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39. Washington State Department of Transportation. *2012-2013 D.O.T Salt Price Comparison & 5 Year Average Use*. October 2012. Available at: http://www.wsdot.wa.gov/NR/rdonlyres/DFEBFA2B-5A42-49BA-82A9-3FBF4AEF258F/0/SaltCompMap.pdf.

40. Department of Transportation RITA ITS JPO. *Benefit-Cost Assessment of a MDSS Implementation: The City and County of Denver*; December 2009; Available at: http://ntl.bts.gov/lib/33000/33100/33156/denver_mdss_bca_report_final.pdf.

41. Department of Transportation, Office of Policy. *Highway Statistics.* 2010. Available at: http://www.fhwa.dot.gov/policyinformation/statistics.cfm.

42. Zhirui Ye, Christopher K. Strong, Xianming Shi, Steven M. Conger, and David L. Huft. *Benefit–Cost Analysis of Maintenance Decision Support System*, Transportation Research Record: Journal of the Transportation Research Board, No. 2107, Transportation Research Board of the National Academies, Washington, D.C., pp. 95–103. 2009. Available at: http://www.coe.montana.edu/me/faculty/Shi/MDSS-CostBenefit.pdf.

43. Washington State Department of Transportation. *2012-2013 D.O.T Salt Price Comparison & 5 Year Average Use*. October 2012. Available at: http://www.wsdot.wa.gov/NR/rdonlyres/DFEBFA2B-5A42-49BA-82A9-3FBF4AEF258F/0/SaltCompMap.pdf.

Information for Maintenance and Fleet Management Systems – This application will add value to the Enhanced Maintenance Decision Support System and will also provide valuable data on the health of the equipment used for snow and ice removal and other weather maintenance vehicles. Continuous monitoring of the fleet health will lead to cost savings associated with breakdowns and other unroutine maintenance. At this time of this analysis, the data on potential fleet health monitoring benefits was too limited to include in the results; however, as this information becomes available, it will be incorporated into the analysis and is expected to increase the non-safety benefits of the road weather management connected vehicle applications.

Variable Speed Limits for Weather-Responsive Traffic Management – This application is likely to produce mobility and associated environmental benefits by smoothing the flow of traffic during adverse weather. While variable speed limits have been well studied and there is a great deal of information on the benefits of smoothing traffic, there is limited data on the smoothness of traffic during adverse weather and the potential increase in smoothness that may be experienced with a weather responsive variable speed limit. As this information becomes available, it will be incorporated into the analysis and is expected to increase the non-safety benefits of the road weather management connected vehicle applications.

Motorist Advisories and Warnings – This application can relieve both incident related and non-incident related congestion. The primary purpose of this application is to provide information on road weather conditions that can lead to increased safety. The direct safety benefits – reduced crashes – lead to secondary mobility and environmental benefits. The analysis evaluates the incident related congestion; however, there may be additional benefits realized from non-incident related congestion and this will be evaluated as more information becomes available. Annually, people waste 1.2 billion hours in crash related congestion[44]. The efficacy of this application for safety benefits was estimated at 20 percent based on a study conducted in Finland on the behavioral impacts of drivers to weather alerts and the associated safety benefits[45]. The incidence, for mobility and environmental benefits, is the number of hours spent in crash related congestion under adverse weather conditions.

To estimate the incidence, the total number of hours spent in crash related congestion is multiplied by 24 percent (the proportion of crashes that occur under adverse weather) and further reduced due to the fact that less people travel during adverse weather and the reduction in volume will lead to less congestion. Adverse weather reduces vehicle volume by approximately 15 percent[46], so this is used to estimate the final incidence as: 1.2 billion * 24% * 85% which equals 244,800,000 hours. The incidence is multiplied by the effectiveness (20%) yielded a total potential hours saved of 48,960,000. This will be further reduced based on deployment assumptions. The number of person hours saved is monetized using the VTTS assuming that this application primarily reduces time wasted by passenger vehicle occupants.

Time spent in congestion is associated with wasted fuel. The amount of fuel wasted on average for vehicles in congestion was estimated using a fuel savings to travel time savings ratio from a study on performance

44. Department of Transportation, *Road Weather Management Program Road Weather Management in Low Visibility Conditions*. 2004. Available at: http://www.topslab.wisc.edu/resources/NHVC_presentations/Regina_McElroy.pdf.

45. Kumala, Rämä. *The Effects of Weather and Road Condition Warnings on Driver Behaviour*. 2nd World Congress on Intelligent Transport Systems, Technical Research Centre of Finland (VTT).1995

46. Department of Transportation, *Road Weather Management. Arterial Operations in Adverse Weather*, Available at http://ops.fhwa.dot.gov/weather/resources/publications/fhwa/ite04_artopsadvewthr.doc.

measures; the ratio is for every 29.98 hours spent in congestion, 5.06 gallons of fuel are wasted[47]. This ratio multiplied by the number of hours saved (29.98 hours ÷ 5.06 gallons * 48,960,000 hours) equals 8,263,429 gallons. This represents the maximum potential gallons saved by the application; this value will be reduced based on the deployment assumptions and monetized as previously described.

Fuel savings in turn result in reductions in GHG and criteria pollutant emissions. To estimate the volumes of emissions savings based on the gallons of fuel saved, the EPA's emission conversion factors were utilized[48]. Table 7 provides the conversion factors.

Table 7. Fuel Savings Conversion Factors (EPA)

	Grams Saved				
	GHGs (Carbon Dioxide)	**Particulate Matter**	**Hydro-carbons**	**Carbon Monoxide**	**Nitrous Oxide**
1 Gallon Fuel Saved =	8,849	0.118	32.6	297	22.8

Source: Booz Allen Hamilton, January 2013.

Based on the conversion factors, the application could potentially reduce GHG emissions by (8,263,429 * 8,849 ÷ 1,000,000 (grams to tons)) 73,122 tons per year. The application could reduce particulate matter emissions by (8,263,429 * 0.118 ÷ 1,000,000 (grams to tons)) 1 ton. Hydrocarbons could be reduced by (8,263,429 * 32.6 ÷ 1,000,000 (grams to tons)) 270 tons. Carbon dioxide could be reduced by (8,263,429 * 297 ÷ 1,000,000 (grams to tons)) 2,457 tons. Nitrous oxide emission could be reduced by (8,263,429 * 22.8 ÷ 1,000,000 (grams to tons)) 188 tons. Each of these values represent the maximum potential emissions saved by the application; this value will be reduced based on the deployment assumptions and monetized as previously described.

Information for Freight Carriers – This application can provide freight drivers critical information about road weather conditions and help them to avoid incident and non-incident related congestion. Similar to motorist advisories and warnings, the efficacy of this application is expected to be 20 percent, which represents the proportion of incident and non-incident related congestion that freight carriers can avoid to incur non-safety benefits. The analysis evaluates both incident related and non-incident related congestion. The incidence, therefore, is the number of hours that freight vehicles spend in congestion under adverse weather conditions.

The incidence of freight vehicle hours spent in congestion under adverse weather conditions is estimated by the Department of Transportation at 32.6 billion[49]. The incidence is multiplied by the effectiveness (20%) yielding a total potential of hours saved of 6.5 billion. This will be further reduced based on deployment assumptions. The number of freight vehicle hours saved is monetized using the VFTTS, which takes into account the driver's wages, freight opportunity cost, and additional operations and maintenance of the vehicle associated with the delay.

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47. Chang, Gang-Len, Ying Liu, Pei Wei Lin, Nan Zou, and Jean Yves Point-Du-Jour. *Performance Evaluation of Chart: Year 2002*. 2003. Available at: http://www.ops.fhwa.dot.gov/congestion_report/chapter4.htm.

48. Environmental Protection Agency. *Emission Facts: Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks*. 2007. Available at: http://www.epa.gov/otaq/consumer/420f08024.pdf.

49. Department of Transportation, Road Weather Management Program. *How Do Weather Events Impact Roads?* Available at: http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm.

The congestion will also result in fuel wasted as described for the motorist advisory and warning application. The fuel savings to travel time savings ratio as previously described was used to estimate gallons of fuel saved. This ratio multiplied by the number of hours saved (29.98 hours ÷ 5.06 gallons * 6.5 billion hours) equals 1.1 billion gallons. This represents the maximum potential gallons saved by the application; this value will be reduced based on the deployment assumptions and monetized as previously described.

Fuel savings in turn result in reductions in GHG and criteria pollutant emissions. Using the EPA conversion factors previously describe, the application could potentially reduce GHG emissions by (1.1 billion * 8,849 ÷ 1,000,000 (grams to tons)) 9,737,709 tons per year. The application could reduce particulate matter emissions by (1.1 billion * 0.118 ÷ 1,000,000 (grams to tons)) 129 tons. Hydrocarbons could be reduced by (1.1 billion * 32.6 ÷ 1,000,000 (grams to tons)) 35,890 tons. Carbon dioxide could be reduced by (1.1 billion * 297 ÷ 1,000,000 (grams to tons)) 327,229 tons. Nitrous oxide emission could be reduced by (1.1 billion * 22.8 ÷ 1,000,000 (grams to tons)) 25,070 tons. Each of these values represent the maximum potential emissions saved by the application; this value will be reduced based on the deployment assumptions and monetized as previously described.

Information and Routing Support for Emergency Responders – There may be limited mobility and environmental benefits associated with the expected reduction in crashes; however, the amount of congestion associated with ambulance crashes is not likely to be in line with national average incident related congestion and there is not enough information to estimate the congestion impact at this time. These benefits may be estimated if more information becomes available; it is not expected to provide significant additions to the non-safety benefits.

Weather-Responsive Signal Timing – This application is designed to optimize safety and traffic throughput at signalized intersections during adverse weather conditions. Due to changes in driving behavior, normal signal operations lead to travel time delays through intersections under adverse weather conditions. A study compared the travel time through a signalized intersection during adverse weather conditions with a normal signal timing algorithm and a weather optimized signal algorithm. This study reported average savings of 4 seconds per vehicle that crossed the intersection[50]. This BCA estimated the efficacy of the application therefore as 4 seconds travel time savings per signalized intersection vehicle crossing; converted to hours the benefit is 0.001 hours per intersection crossing.

To estimate the incidence, it was necessary to determine the number of signalized intersection vehicle crossings that occur under adverse weather conditions. To achieve this, first the number of annual signal crossings was estimated using the following calculation:

1) Arterial VMT ÷ Arterial Road Miles = Average Traffic Volume
2) Average Traffic Volume * 2 Roads per Signalized Intersection = Signalized Intersection Crossings
3) Signalized Intersection Crossings * Signalized Intersections = Total Signal Crossings

The annual Arterial VMT and the Arterial Road Miles are derived from the Department of Transportation Highway Statistics[51]. The number of signalized intersections is based on the estimate that there is one

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50. Maki, Pamela J. *Adverse Weather Traffic Signal Timing.* Available at: http://trafficware.infopop.cc/downloads/00005.pdf.

51. Department of Transportation, Office of Policy. *Highway Statistics.* 2010. Available at: http://www.fhwa.dot.gov/policyinformation/statistics.cfm.

signalized intersection per 1,000 people from the Federal Highway Administration[52]. Based on this calculation, there are 1.4 trillion signal crossings per year.

Assuming that 24 percent of crossings occur under adverse conditions and that volume is further reduce by 15 percent, the number of signal crossings under adverse weather conditions is 286 billion; this is th e incidence. Multiplying the incidence by the efficacy (travel time savings of 0.001 hours per intersection crossing) yields an annual travel time savings of 317,433,364 hours. The value is further reduced by the deployment scenario; assuming this benefit will only be realized if the intersection has an RSE. The analysis assumes the benefit is predominantly passenger vehicle traffic and monetizes the travel time savings using the VTTS.

The reduced travel time will have fuel saving benefits. The fuel savi ngs to travel time savings ratio as previously described was used to estimate gallons of fuel saved. This ratio multiplied by the number of hours saved (29.98 hours ÷ 5.06 gallons * 317,433,364 hours) equals 53,576,145 gallons. This represents the maximum potential gallons saved by the application; this value will be reduced based on the deployment assumptions and monetized as previously described.

Fuel savings in turn result in reductions in GHG and criteria pollutant emissions. Using the EPA conversion factors previously describe, the application could potentially reduce GHG emissions by (53,576,145 * 8,849 ÷ 1,000,000 (grams to tons)) 474,091 tons per year. The application could reduce particulate matter emissions by (53,576,145 * 0.118 ÷ 1,000,000 (grams to tons)) 6 tons. Hydrocarbons could be reduced by (53,576,145 * 32.6 ÷ 1,000,000 (grams to tons)) 1,747 tons. Carbon dioxide could be reduced by (53,576,145 * 297 ÷ 1,000,000 (grams to tons)) 15,932 tons. Nitrous oxide emission could be reduced by (53,576,145 * 22.8 ÷ 1,000,000 (grams to tons)) 1,221 tons. Each of these values represent the maximum potential emissions saved by the application; this value will be reduced based on the deployment assumptions and monetized as previously described.

52. Department of Transportation, Federal Highway Administration. *Manual on Uniform Traffic Control Devices*. 2012. Available at: http://www.mutcd.fhwa.dot.gov/knowledge/faqs/faq_part4.htm#q1.

Cost Estimation

There are three categories of costs considered in the analysis: CVE core costs, road weather specific connected vehicle costs, and application specific costs. The first set of costs is incurred regardless of which applications are deployed and can be used by all connected vehicle applications including those designed for purpose other than road weather management. The second set of costs is required for all road weather connected vehicles to function but is not specific to any particular application. The final set of costs are specific to each of the applications.

CVE Core Costs

The CVE Core costs are described in the scenario deployment section. The cost elements that are included in the CVE core are RSE development, RSE installation and maintenance and operation, OBE installation and maintenance and operation, and network backhaul and recurring costs.

RSE Installation, Operating, and Maintenance Costs

The cost of RSE development is $6 million that is all incurred upfront.[53] RSE installation and maintenance and operations costs differ based on the location and whether or not the RSE will have access to the power grid. The costs for RSEs are displayed in Table 8 below.

Table 8. RSE Costs[54]

RSE Type/Location	Installation Cost	Number of Units Installed	Total Installation Cost
Urban Freeway RSE with wireline	$9,600	5,000	$48,000,000
Urban Freeway RSE with wireless	$20,300	20,000	$406,000,000
Urban Signal RSE with wireline	$11,600	42,000	$487,200,000
Urban Signal RSE with wireless	$22,300	168,000	$3,746,400,000
Rural Interstate with power grid connection	$29,300	13,600	$398,480,000
Rural Interstate without power grid connection	$37,100	3,400	$126,140,000
Total RSE Installation Costs			**$5,212,220,000**

Source: Booz Allen Hamilton, January 2013.

53. Department of Transportation Volpe Center. *Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis*. May 8, 2008.

54. Ibid.

The installation costs are incurred equally over the five year installation period. During that period and through the end of the analysis, each type of RSE is expected to incur an operations and maintenance cost of 10% of the installation cost.

OBE Installation, Operating, and Maintenance Costs

The initial installation cost of an OBE unit is expected to be $50. The expected life of the unit is 12 years with replacement of the unit costing $100. Short of the 12 year life, it is expected that there will be some units that break before their design life is over; due to this there is an ongoing cost incurred of two percent of the replacement cost. Based on all of these factors the equivalent annual cost (the adjusted cost annually taking into account that installation costs will be incurred in the first year) is $6. The $6 unit cost per OBE unit is multiplied by the number of OBEs in any given year based on the assumptions described in the deployment scenario section. In 2055, the total annual OBE cost is $2 billion.

Network Backhaul, Operating, and Maintenance Costs

To enable a DSRC network to function as required by the road weather applications there needs to be a backhaul to increase the volume of data that can be sent over DSRC and there will also be an ongoing cost associated with maintaining the network functionality. To increase the capability of the network to allow all of the road weather applications to function properly, the total cost is estimated at $221,500,000 that will be incurred between 2015 to 2019. The ongoing cost will $353,700,000.[55]

Road Weather Specific Costs

In addition to the CVE core costs, the road weather connected vehicle applications are reliant on the VDT. This cost is not associated with any specific application and will be leveraged by all road weather applications so was isolated in the analysis from the application specific costs. The VDT installation costs are expected to be $10 million per year for five years (2015 – 2019) assuming that ten TMCs will install a VDT each year. The ongoing operations and maintenance costs for the VDT are estimated to be ten percent of the initial cost ($1 million per year). This estimate is based on expert RWMP judgment due to the fact that there are not currently better estimates available in the literature.

Application Specific Costs

There are a number of application specific costs that are incremental to the installation and maintenance and operation of the additional applications. The cost elements required for some or all of the applications are: maintenance vehicle environmental sensors, application development, system integration and backoffice costs, education and outreach, incremental OBE costs.

Maintenance Vehicles Will Have Environmental Sensor

Some of the applications will utilize environmental sensors on maintenance vehicles for additional information. For each maintenance vehicle (in current analysis, snowplows are substituted), there is a capital cost of

55. Department of Transportation Volpe Center. *Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis*. May 8, 2008.

$30,000 with a life of 5 years, or an equivalent annual cost of $6,000 per vehicle. The operating and maintenance cost is $500. The total annual cost, therefore, is $6,500.[56]

Application Development

The Volpe Center BCA includes an estimate of the one-time cost for developing each application. As reported in that study, "these costs represent the incremental development costs for each additional application. Examples include development of software and algorithms, creating map databases, or designing human-machine interfaces (HMI) and warning protocols." The estimated upfront cost of developing a new connected vehicle application is $10 million. This BCA utilizes a one-time, nationwide, upfront cost of $10 million.[57]

System integration and Backoffice Costs

There are costs associated with integrating the application into the current system including the infrastructure, conventional ITS, and operations. This cost is incurred per TMC, per application. The estimated capital cost is $1,350,000 with a life of 35 years; yielding an equivalent annual cost of $38,571. The ongoing operations and maintenance costs which include the necessary increase in labor and backoffice costs of managing application data is estimated at $200,000; with a total annual cost of $238,571.[58]

Education and Outreach

Due to the nature of many of the applications requiring the driver to respond to information provided, it is likely that the TMC or DOT will engage in an outreach program to provide education on the application and ensure better use. A 2008 report by the National Cooperative Highway Research Program notes that media, education, and outreach would occur in waves, with each wave costing approximately $0.03 to $0.06 per capita. The study based its estimate on cost data from various states for the "Click It or Ticket" campaign. This BCA assumes that there will be one wave of outreach per year, with an annual operations cost of $0.045 cents per capita.[59]

Incremental OBE

The Volpe Center BCA estimates that an application will likely increase the annual operations and maintenance costs for an OBE. As stated in the report, "the magnitude of these costs is not yet clear. However, just as each application installed on a personal computer adds slightly to operating costs and to the chance that repairs or software upgrades will be needed, so does each VII safety application add slightly to the maintenance cost of the OBE." That study estimates that the cost of replacing a failed OBE is $100. It further estimates that the typical failure rate is 2 percent per year, but the incremental complexity from adding a new application increases the failure rate by 5 percent to 2.1 percent per year. The incremental expected annual

56. Kack, David, and Eli Cuelho. *Needs Assessment and Cost-Benefit Analysis of RoadView (TM) Advanced Snowplow Technology System.* Proceedings of the Sixth International Symposium on Snow Removal and Ice Control Technology, Spokane, Washington, Transportation Research Board; June 7-9 2004; http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf.

57. Department of Transportation Volpe Center. *Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis*. May 8, 2008.

58. In Spokane, enhancements to a regional TMC for advanced traveler information systems was $1,238,679. In Louisiana, integrating weather information into TMC operations cost $314,500 upfront with $49,500 annual O&M. A similar upgrade in Wyoming cost $6.27M up front with $833K O&M. A logarithmic average was taken for these three cases. http://www.benefitcost.its.dot.gov.

59. "Guidance for Implementation of the AASHTO Strategic Highway Safety Plan", The cost of the "Click-It or Ticket" campaign costs 3-6 cents per capita. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v22.pdf, NCHRP. p. V-84.

cost for OBE due to this assumption is calculated below in Table 9; the annual O&M for incremental OBE costs of $0.10 per vehicle equipped with an OBE. [60]

Table 9. OBE Incremental Cost Calculation

Scenario	Replacement Cost	Annual Failure Rate	Expected Annual Failure Cost	Incremental Annual Cost
Baseline	$100	2%	$2.00	-
With Application	$100	2.1%	$2.10	$0.10

Source: Booz Allen Hamilton, January 2013.

Variable Speed Limit Sign

This analysis assumes that the variable speed limits for weather-responsive traffic management application will require a large dynamic message sign on freeways since not all vehicles will have OBEs in the near term. The ITS-JPO Benefit Cost website contains a 2005 estimate for the cost parameters of a dynamic message sign. [61] The estimated capital cost for the equipment and installation ranges from $47,000 to $117,000, the annual operations and maintenance cost is from $2,300 to $6,000, and the expected lifespan is 10 years. For the purposes of this study, average values were used, resulting in a capital cost of $82,000, an ongoing cost of $4,150, and a lifespan of 10 years.

The cost elements described above are held constant for each of the applications; however, not all of the applications require all of the cost element. Table 10 illustrates which applications will require which of the cost elements (denoted by a checkmark).

Table 10. Application Cost Element Matrix

Application	Maintenance Vehicles will have ESS	Application Development	System integration and backoffice costs	Education and Outreach	Incremental OBE	Variable Speed Limit Sign
Enhanced Maintenance Decision Support System	√	√	√	√	√	
Information for Maintenance and Fleet Management Systems		√	√		√	
Variable Speed Limits for Weather-Responsive Traffic Management		√	√	√	√	√
Motorist Advisories and Warnings		√	√	√	√	
Information for Freight Carriers		√	√		√	
Information and Routing Support for Emergency Responders		√	√		√	
Weather-Responsive Signal Timing		√	√	√	√	

Source: Booz Allen Hamilton, January 2013.

60. Department of Transportation Volpe Center. *Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis*. May 8, 2008.

61. Department of Transportation Volpe Center. *Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis*. May 8, 2008.

The unit costs described in this section will vary per year based on the integration of the deployment scenario. Table 11 shows the formulas used to extrapolate the costs for each of the applications; these formu las remain constant for each year of the analysis, while the values will change.

Table 11. Cost Extrapolation Formulas

Application	Cost Extrapolation
Enhanced Maintenance Decision Support System	*[Maintenance Vehicle ESS Cost Element × Application Implementation (%) × Number of Snowplows] + [Application Development Cost (one-time)] + [System Integration and Backoffice Cost Element × Application Implementation (%) × TMCs] + [Education Cost Element × Application Implementation (%) × Population] + [Incremental OBE Cost Element × Application Implementation (%) × Number of Connected Vehicles] = Annual Cost*
Information for Maintenance and Fleet Management Systems	*[Application Development Cost (one-time)] + [System Integration and Backoffice Cost Element × Application Implementation (%) × TMCs] + [Incremental OBE Cost Element × Application Implementation (%) × Number of Connected Vehicles] = Annual Cost*
Variable Speed Limits for Weather-Responsive Traffic Management	*[Application Development Cost (one-time)] + [System Integration and Backoffice Cost Element × Application Implementation (%) × TMCs] + [Education Cost Element × Application Implementation (%) × Population] + [Incremental OBE Cost Element × Application Implementation (%) × Number of Connected Vehicles] + [Variable Speed Limit Cost Element Application Implementation (%) × 1/3 of Freeway Miles] = Annual Cost*
Motorist Advisories and Warnings	*[Application Development Cost (one-time)] + [System Integration and Backoffice Cost Element × Application Implementation (%) × TMCs] + [Education Cost Element × Application Implementation (%) × Population] + [Incremental OBE Cost Element × Application Implementation (%) × Number of Connected Vehicles] = Annual Cost*
Information for Freight Carriers	*[Application Development Cost (one-time)] + [System Integration and Backoffice Cost Element × Application Implementation (%) × TMCs] + [Incremental OBE Cost Element × Application Implementation (%) × Number of Connected Vehicles] = Annual Cost*
Information and Routing Support for Emergency Responders	*[Application Development Cost (one-time)] + [System Integration and Backoffice Cost Element × Application Implementation (%) × TMCs] + [Incremental OBE Cost Element × Application Implementation (%) × Number of Connected Vehicles] = Annual Cost*
Weather-Responsive Signal Timing	*[Application Development Cost (one-time)] + [System Integration and Backoffice Cost Element × Application Implementation (%) × TMCs] + [Education Cost Element × Application Implementation (%) × Population] + [Incremental OBE Cost Element × Application Implementation (%) × Number of Connected Vehicles] = Annual Cost*

Source: Booz Allen Hamilton, January 2013.

The net benefits for each application are calculated by simply subtracting the extrapolated costs from the extrapolated benefits.

National Extrapolation

Extrapolation of the data takes into account all of the previously described assumptions, in particular the deployment scenario, some additional data points, and estimates the likely total annual U.S. benefits and costs of each of the road weather connected vehicle applications. There are a number of key factors utilized to extrapolate the benefits and costs; these factors are: application implementation deployment rate, connected vehicle infrastructure (% vehicles with an OBE), connected vehicle infrastructure (number of vehicles with an OBE), population (driving age only), the number of snowplows in the U.S., the number of TMCs, the application maturity effectiveness factor, national freeway miles, road side equipment availability (% of connectivity), and signal RSEs availability (% of connectivity).

The application implementation deployment rate, connected vehicle infrastructure (% vehicles with an OBE), and the application maturity effectiveness factor were described in the deployment scenario section. The number of vehicles with OBE is calculated as previously described. The population is derived from the Department of Energy Annual Energy Outlook 2011 forecast for population growth (16 and over).[62] The number of snowplows is estimated to be 1,066,900 based on the U.S. Department of Commerce Vehicle Inventory Survey.[63] The number of TMCs used for the analysis is 266 based on the number of surveys distributed by for a Deployment Survey of Traffic Management Centers conducted by the Department of Transportation.[64] The number of national freeway miles is derived from the Federal Highway Administration Highway Statistics.[65] Finally road side and signal RSE availability are based on phased connectivity over the five year installation period, with connectivity of urban and rural freeway reaching 100 percent, while signal connectivity reaches 70 percent of urban signals only.

These extrapolation factors are utilized along with the annual benefits and cost estimates to derive the expected values for each year and the entire period. The calculation to estimate the extrapolated value for the benefits and costs for each application varies slightly (based on their technical requirements) and the formulas to estimate safety benefits and costs are described below. Non-safety benefits are calculated similarly, however, the value as described in the non-safety benefits section replace the safety unit value (e.g. rather than fatalities avoided ($) it would be fuel saved ($)). Table 12 shows the formulas used to extrapolate the benefits for each of the applications; these formulas remain constant for each year of the analysis, while the values will change.

62. Department of Energy, Energy Information Administration. *Annual Energy Outlook 2011, Reference Case*. May 2011.

63. Department of Commerce, Economics and Statistics Administration, U.S. CENSUS BUREAU, *2002 Vehicle Inventory and Use Survey*, available at: http://www.census.gov/svsd/www/vius/2002.html.

64. DOT RITA ITS. *Deployment Survey of Traffic Management Centers*; Available at: http://www.itsdeployment.its.dot.gov/TMC.aspx.

65. DOT FHWA. *Highway Statistics*. Available at: http://www.fhwa.dot.gov/policyinformation/statistics.cfm.

Table 12. Benefit Extrapolation Formulas

Application	Benefit Extrapolation
Enhanced Maintenance Decision Support System	*[Fatalities Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Injuries Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Property Damage Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] = Annual Benefit*
Information for Maintenance and Fleet Management Systems	*[Fatalities Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Injuries Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Property Damage Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] = Annual Benefit*
Variable Speed Limits for Weather-Responsive Traffic Management	*[Fatalities Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Injuries Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Property Damage Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)]= Annual Benefit*
Motorist Advisories and Warnings	*[Fatalities Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Injuries Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Property Damage Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] = Annual Benefit*
Information for Freight Carriers	*[Fatalities Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Injuries Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Property Damage Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] = Annual Benefit*
Information and Routing Support for Emergency Responders	*[Fatalities Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Injuries Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] + [Property Damage Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Road Side Equipment Availability (%)] = Annual Benefit*
Weather-Responsive Signal Timing	*[Fatalities Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Signal RSEs Availability (%)] + [Injuries Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Signal RSEs Availability (%)] + [Property Damage Avoided ($) × Application Implementation (%) × Connected Vehicle Infrastructure (%) × Application Maturity Effectiveness Factor (%) × Signal RSEs Availability (%)] = Annual Benefit*

Limitations of the Analysis

Any forward-looking BCA will have limitations due to the nature of assumptions that are required. This BCA is not only evaluating a long time horizon (through 2055) but is assessing the benefits, costs, and deployment of applications that are not currently developed. There are a number of assumptions that impact the results of the analysis and can be considered in six overarching categories: (1) scope of the analysis, (2) baseline, (3) scenario deployment, (4) benefit estimates, (5) cost estimates, and (6) extrapolation factors. Each category is discussed below in more detail.

Scope of the Analysis: The scope of the analysis was limited to the United States; to the extent that the applications provide benefits or incur costs internationally, the results will be under- or over-estimated. The analysis was limited to the safety benefits of the applications; Phase II will evaluate additional benefits that will likely increase the magnitude of the benefit estimates.

Baseline: There are a number of assumptions in the baseline; in particular, it is assumed that conventional ITS will not significantly increase in deployment due to cost. To the extent that conventional road weather management ITS is further deployed, this will erode the potential benefits of the road weather connected vehicle applications (in comparison to the baseline).

Deployment Scenario: There is a great deal of uncertainty related to the deployment of connected vehicle technology; in particular the CVE core. This analysis relies on assumptions about how quickly and how many OBEs, RSEs, and applications will be deployed. To the extent that these are under- or over-estimated, the results of the analysis will also be under- or over-estimated.

Benefit Estimates: The unit benefit estimates are derived from the literature based on the current state of knowledge; many of the applications evaluated in the literature do not leverage connected vehicle technology as the envisioned road weather applications considered in this analysis. In addition, the literature is limited and often case studies are conducted in one area and may not apply in the extrapolation as expected. To the extent that unit benefits are under- or over-estimated, results will be under- or over-estimated.

Cost Estimates: The unit cost estimates are derived from the literature based on the current state of knowledge. This data is limited and may not apply in the extrapolation as expected. To the extent that unit costs are under- or over-estimated, results will also be under- or over-estimated.

Extrapolation Factors: Extrapolation of the benefits and costs of applications rely on the deployment scenario assumptions and the unit benefit and cost estimates. To the extent that the applicability to the nation as a whole is under- or over-estimated, the results will be under- or over-estimated.

There are many limitations to this analysis, but it is still considered valid. The purpose is to identify the potential safety benefits of the road weather connected vehicle applications and compare the monetized benefits to costs of deploying a CVE core. The tools utilized were designed to be flexible and as new, better information becomes available, the analysis will be updated.

Results

The results of the road weather connected vehicle applications BCA are reported in a number of ways so that one can interpret the safety and non-safety benefits of the entire program in comparison to all of the costs associated with deployment, the benefits and costs of the individual applications can be considered and compared, and the qualitative safety and non-safety benefits of the program and applications can be considered. The safety benefits for each of the applications are reported first, followed by the non-safety benefits for each of the applications, and then the combined safety and non-safety benefits, the application specific costs, and the application net benefits (benefits minus costs). The total Program benefits, costs, and net benefits are presented followed by a section comparing the results of the applications.

Safety Benefits

Enhanced Maintenance Decision Support System Results

The enhanced maintenance decision support system application did yield safety benefits including crashes, fatalities, injuries, and property damage avoided. These results are displayed in Table 13.

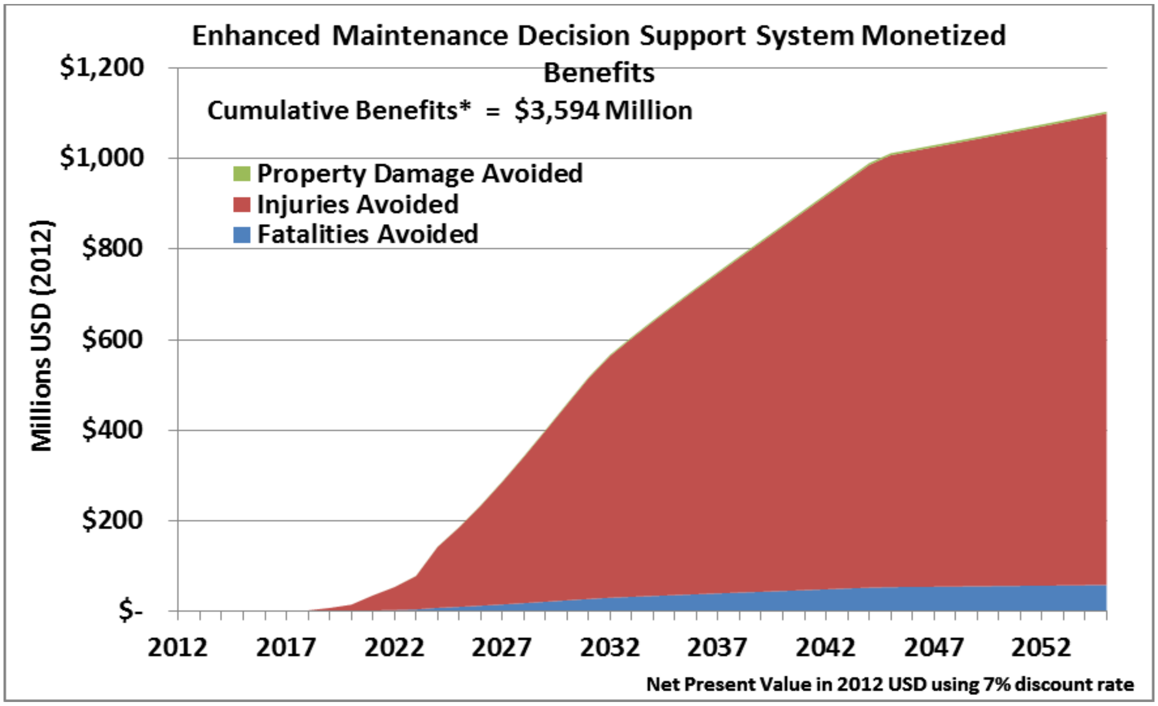
Figure 8 shows the stacked total of monetary value of the safety benefits for each year of the analysis. Injuries contributes the greatest value to the monetized safety benefits.

Table 13. Enhanced Maintenance Decision Support System

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
33,863	160	14,101	$ 16,199,082

Source: Booz Allen Hamilton, January 2013.

Figure 8. Monetized Safety Benefits of Enhanced Maintenance Decision Support System



Source: Booz Allen Hamilton, January 2013.

Information for Maintenance and Fleet Management Systems Results

Safety benefits were not estimated for the information for maintenance and fleet management systems application.

Variable Speed Limits for Weather-Responsive Traffic Management Results

The results for the variable speed limits for weather-responsive traffic management are considered as two subapplications: in work zones and not in work zones. The results for the work zone deployment of the application are described first below.

Variable Speed Limits for Weather-Responsive Traffic Management in Work Zones

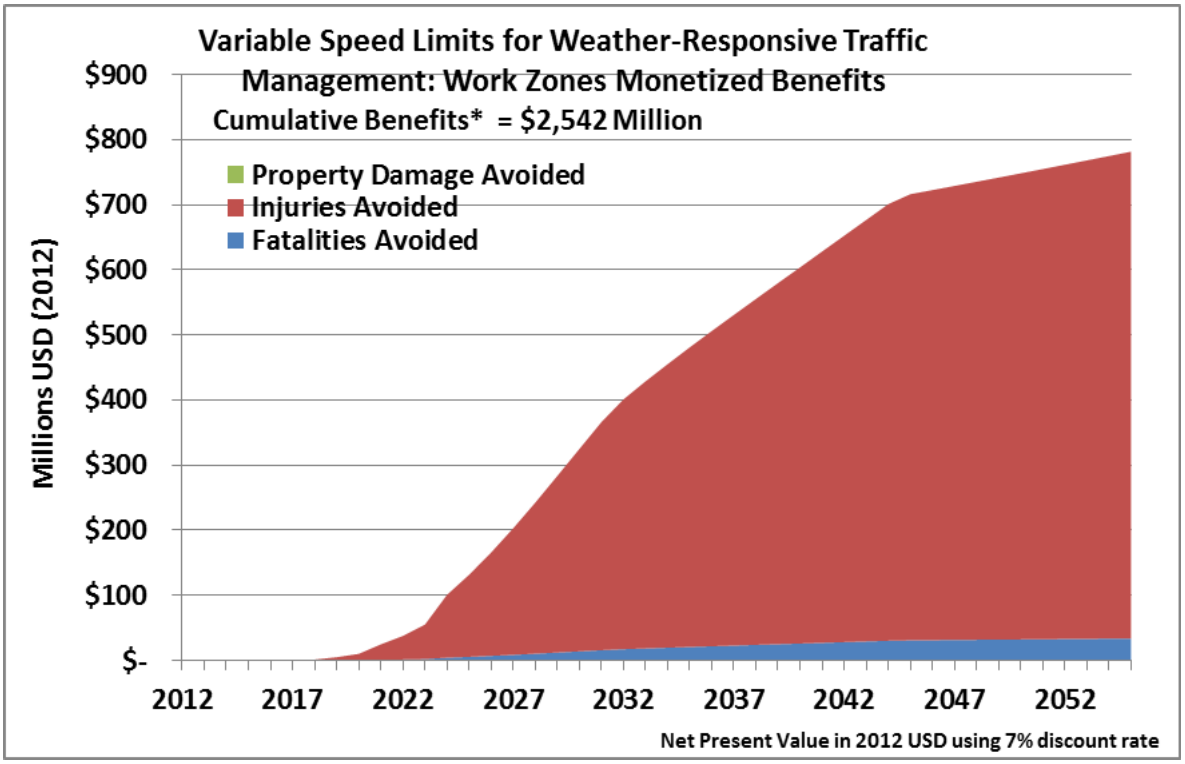
Table 14 provides the qualitative safety benefits of the application deployment for the entire period. Note that property damage avoided is not estimated in work zones, but information is attributed to the non-work zone component of the application. Figure 9 displays the annual stacked total of monetized benefits of the application in work zones. In work zones, the net present value of the safety benefits including fatalities, injuries, and property damage avoided is $2.5 billion for the entire analytical period.

Table 14. Qualitative Safety Benefits of Variable Speed Limits for Weather-Responsive Traffic Management in Work Zones

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
24,389	93	10,124	$ -

Source: Booz Allen Hamilton, January 2013.

Figure 9. Monetized Safety Benefits of Variable Speed Limits for Weather-Responsive Traffic Management in Work Zones



Source: Booz Allen Hamilton, January 2013.

Variable Speed Limits for Weather-Responsive Traffic Management in Non-Work Zones

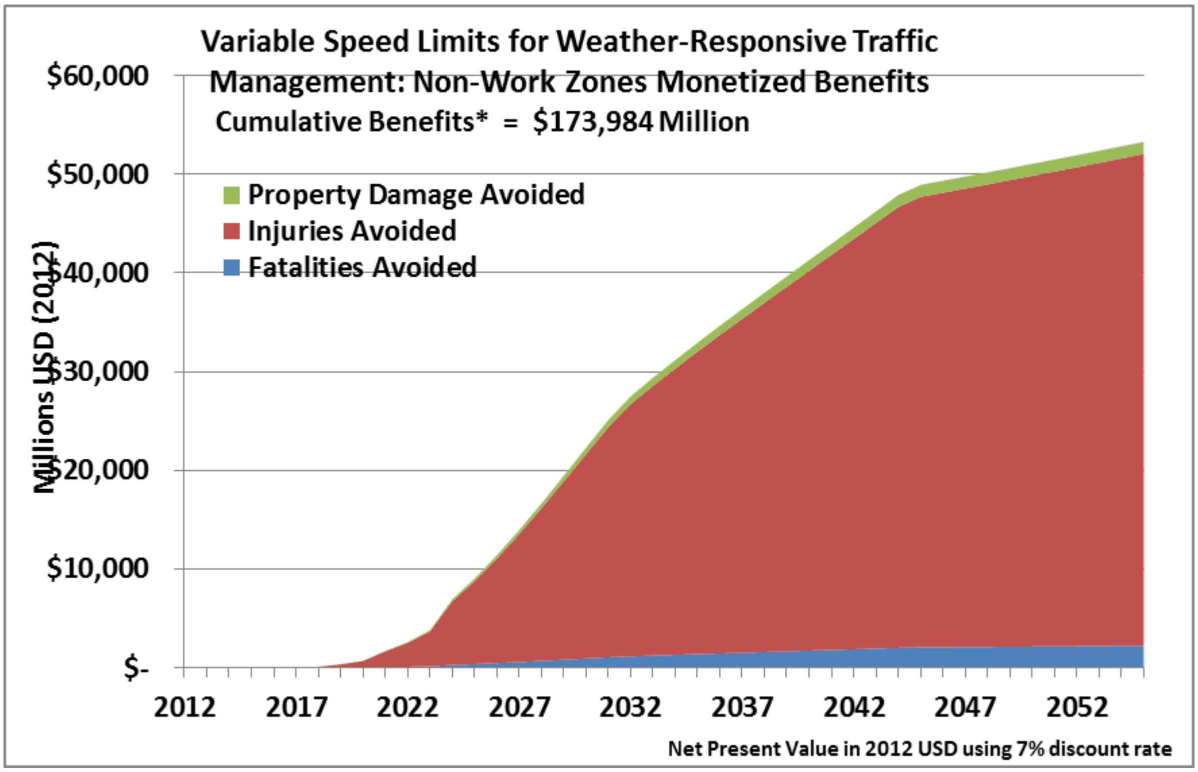
Table 15 provides the qualitative safety benefits of the application deployment for the entire 40-year period. Figure 10 displays the annual stacked total of monetized benefits for each of the safety benefit categories over time. The value of injuries avoided is the greatest contributor to the total monetary value of the safety benefits. The net present value of the safety benefits for the entire 40-year period are $174 billion.

Table 15. Qualitative Benefits of Variable Speed Limits for Weather-Responsive Traffic Management in Non-Work Zones

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
1,624,491	6,203	674,292	$ 4,617,875,497

Source: Booz Allen Hamilton, January 2013.

Figure 10. Monetized Safety Benefits of Variable Speed Limits for Weather Responsive Traffic Management in Non-Work Zones



Source: Booz Allen Hamilton, January 2013.

Motorist Advisories and Warnings Results

Table 16 provides the qualitative safety benefits of the application deployment for the entire 40-year period. This application is estimated to realize nearly 4.5 million crashes avoided with associated reductions to fatalities of almost 21,000 people and 1.8 million injuries avoided.

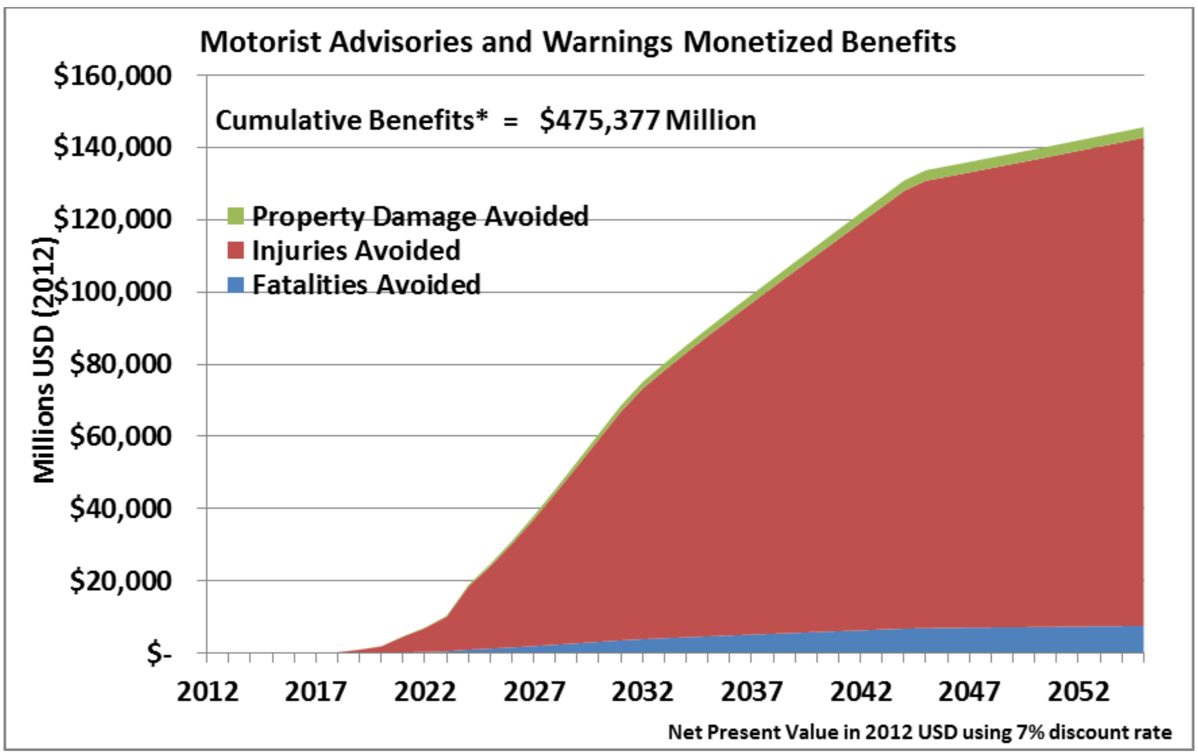
Figure 11 displays the annual stacked total of monetized benefits for each of the benefit categories over time. The value of injuries avoided is the greatest contributor to the total monetary value of the safety benefits. The net present value of the safety benefits for the entire 40-year period are $475 billion.

Table 16. Qualitative Benefits of Motorist Advisories and Warnings

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
4,409,335	20,798	1,830,221	$10,973,169,497

Source: Booz Allen Hamilton, January 2013.

Figure 11. Monetized Safety Benefits of Motorist Advisories and Warnings



Source: Booz Allen Hamilton, January 2013.

Information for Freight Carriers Results

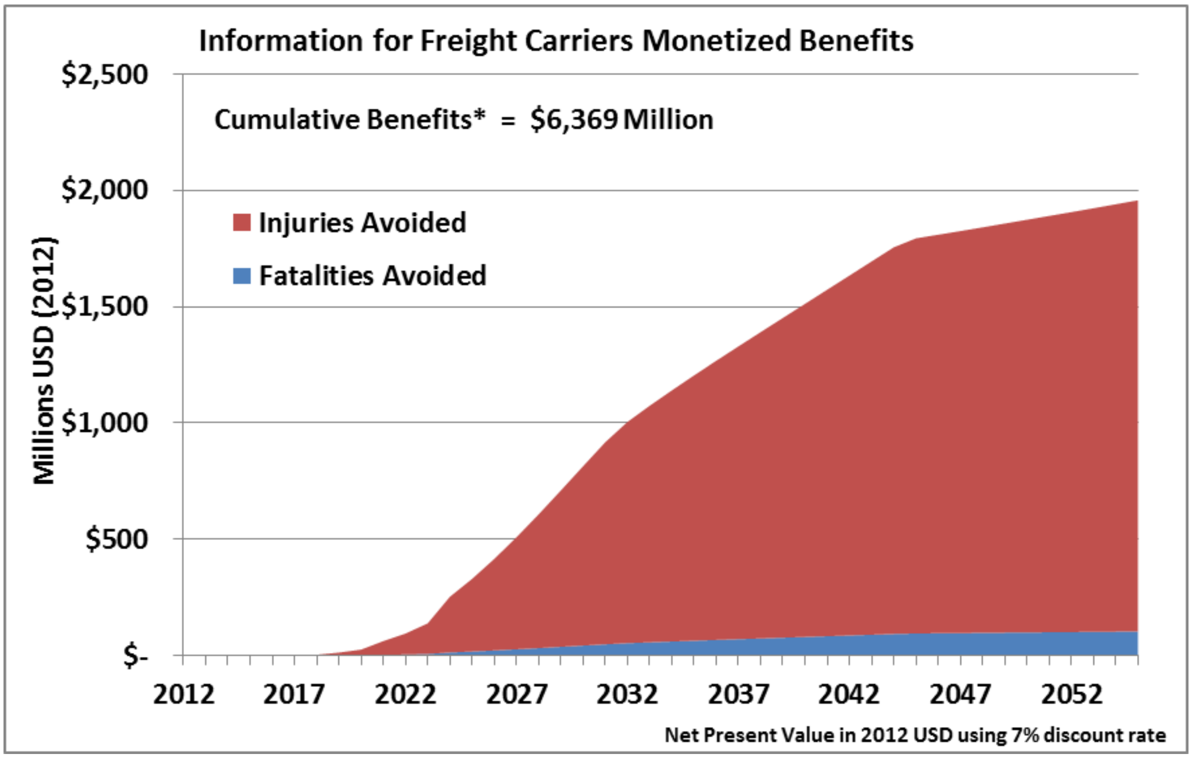
Table 17 displays the qualitative safety benefits estimated for the application including the total number of crashes, fatalities, and injuries avoided. Figure 12 below illustrates the annual stacked total of monetized benefits of the application. Injuries avoided contributes the greatest proportion of the monetized safety benefits.

Table 17. Qualitative Benefits of Information for Freight Carriers

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
60,472	285	25,100	$ -

Source: Booz Allen Hamilton, January 2013.

Figure 12. Monetized Safety Benefits of Information for Freight Carriers



Source: Booz Allen Hamilton, January 2013.

Information and Routing Support for Emergency Responders Results

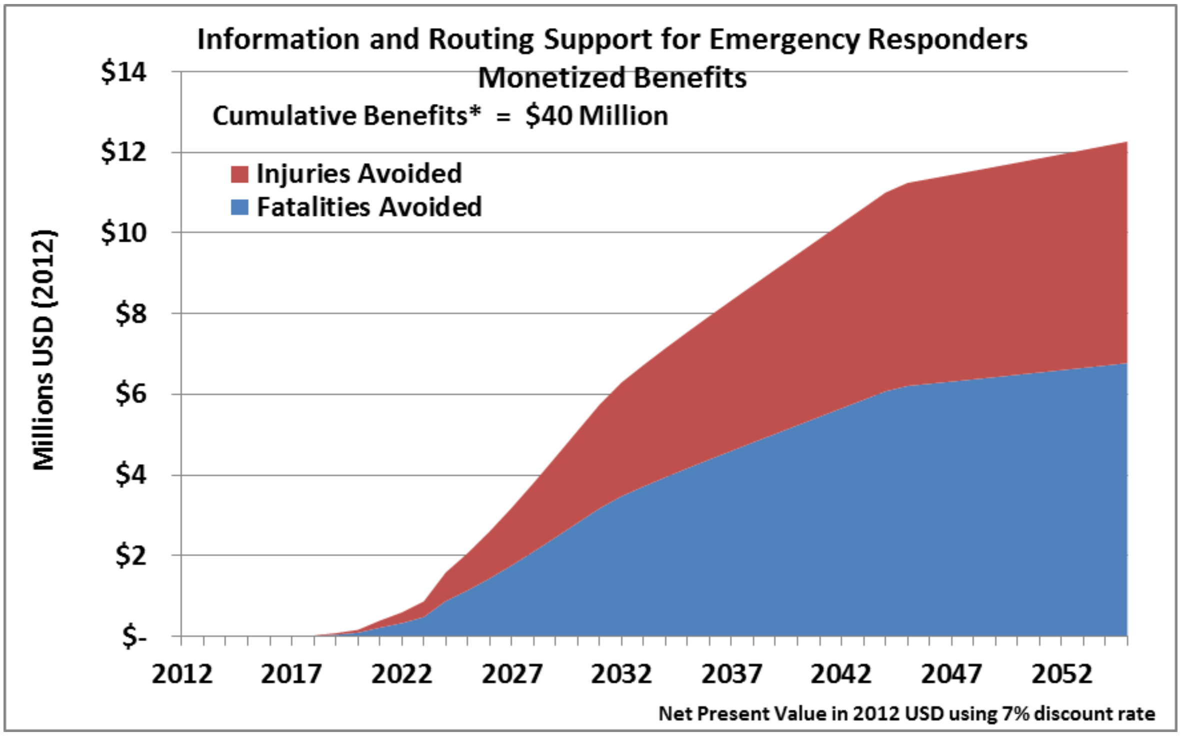
Table 18 displays the qualitative safety benefits estimated for the application including the total number of crashes, fatalities, and injuries avoided. Figure 13 displays the annual stacked total of monetized benefits of the application; this graph illustrates the increasing value of safety benefits over time.

Table 18. Qualitative Benefits of Information and Routing Support for Emergency Responders

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
372	19	74	$ -

Source: Booz Allen Hamilton, January 2013.

Figure 13. Monetized Safety Benefits of Information and Routing Support for Emergency Responders



Source: Booz Allen Hamilton, January 2013.

Weather Responsive Signal Timing Results

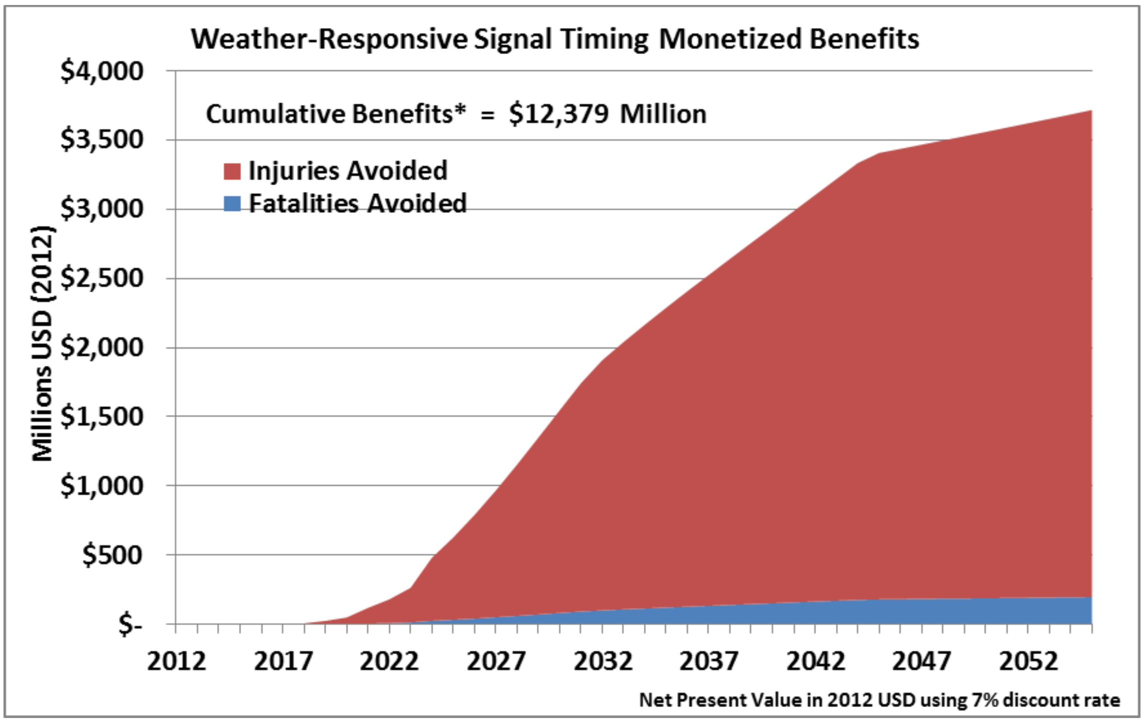
The qualitative safety benefits including the crashes, fatalities, and injuries avoided for the period of analysis as a result of this application are displayed in Table 19. Figure 14 displays the annual stacked total of monetized benefits of the application; this graph illustrates the increasing value of safety benefits over time as the CVE is increasingly deployed.

Table 19. Qualitative Benefits of Weather-Responsive Signal Timing

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
40,407	83	7,278	$ 285,741,334

Source: Booz Allen Hamilton, January 2013.

Figure 14. Monetized Safety Benefits of Weather-Responsive Signal Timing



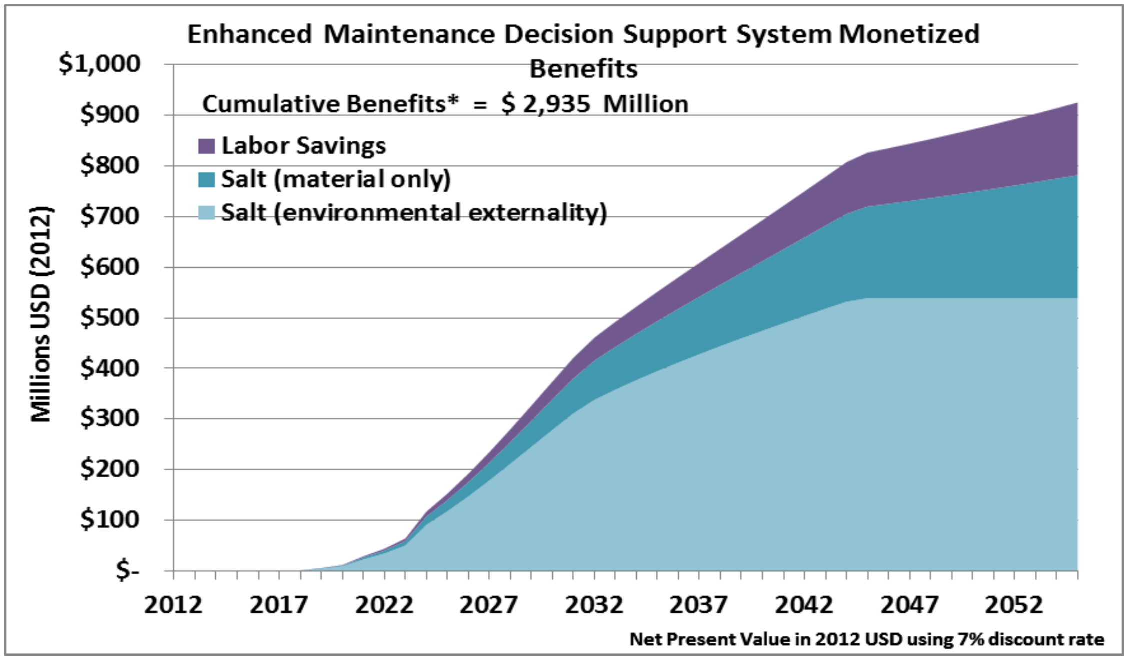
Source: Booz Allen Hamilton, January 2013.

Non-Safety Benefits

Enhanced Maintenance Decision Support System Results

The enhanced maintenance decision support system application was estimated to have considerable operational savings benefits for state and local road weather management programs. The labor savings, material salt savings, and expected benefits to the environment as a result of reduced salt use are illustrated as annual stacked totals for the entire analytical period in Figure 15 below.

Figure 15. Monetized Non-Safety Benefits of Enhanced Maintenance Decision Support System



Source: Booz Allen Hamilton, January 2013.

Information for Maintenance and Fleet Management Systems Results

Non-safety benefits were not estimated for the information for maintenance and fleet management systems application.

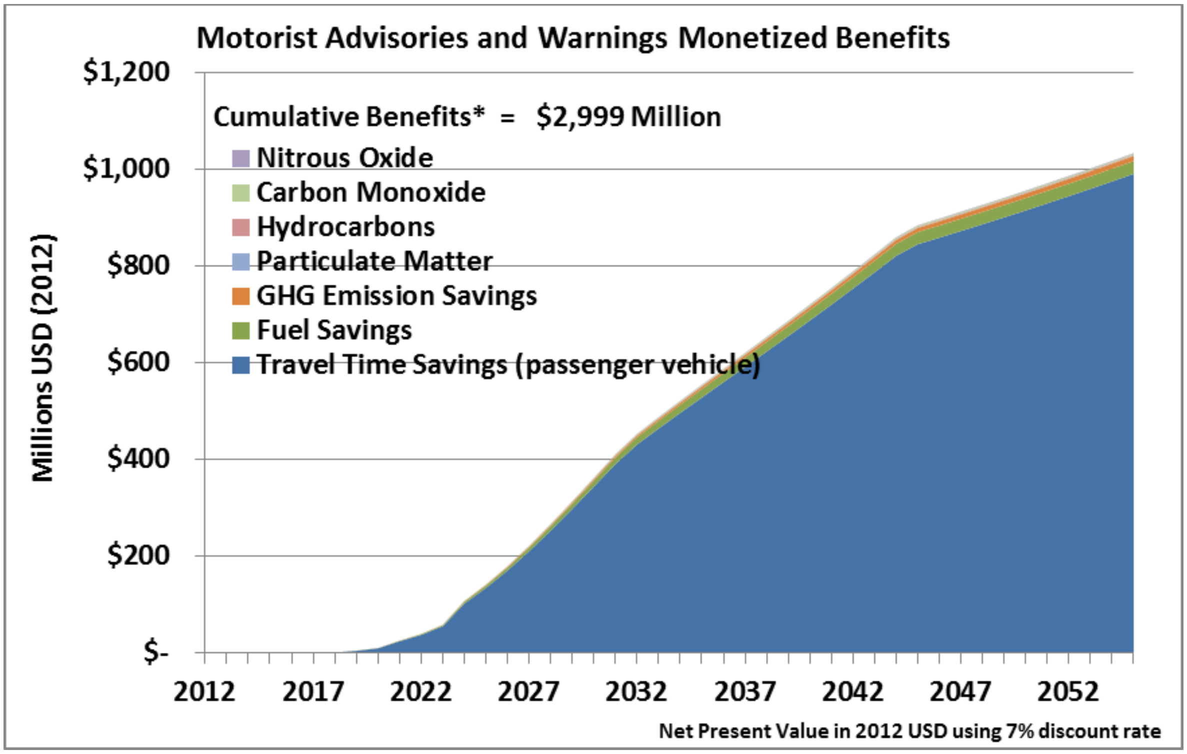
Variable Speed Limits for Weather-Responsive Traffic Management Results

Non-safety benefits were not estimated for the variable speed limits for weather-responsive traffic management application.

Motorist Advisories and Warnings Results

The motorist advisories and warnings application was estimated to have significant mobility and environmental benefits. The monetized travel time savings, fuel savings, and GHG and criteria pollutant emission reductions benefits are displayed as annual stacked totals for the entire analytical period in Figure 16 below.

Figure 16. Monetized Non-Safety Benefits of Motorist Advisories and Warnings

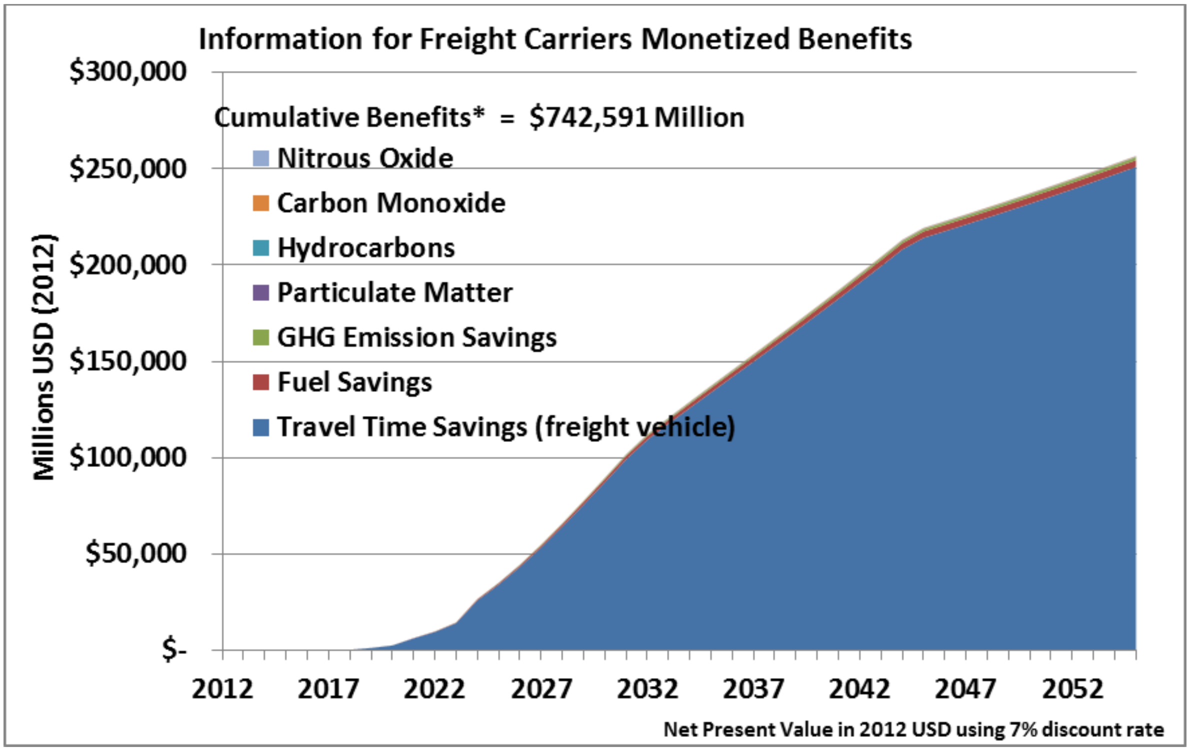


Source: Booz Allen Hamilton, January 2013.

Information for Freight Carriers Results

The information for freight carriers application was estimated to have significant mobility benefits for freight vehicles associated with environmental benefits. The monetized freight travel time savings, fuel savings, and GHG and criteria pollutant emission reductions benefits are displayed as annual stacked totals for the entire analytical period in Figure 17 below. The results for this application reflect the high value of time for freight carriers.

Figure 17. Monetized Non-Safety Benefits of Information for Freight Carriers



Source: Booz Allen Hamilton, January 2013.

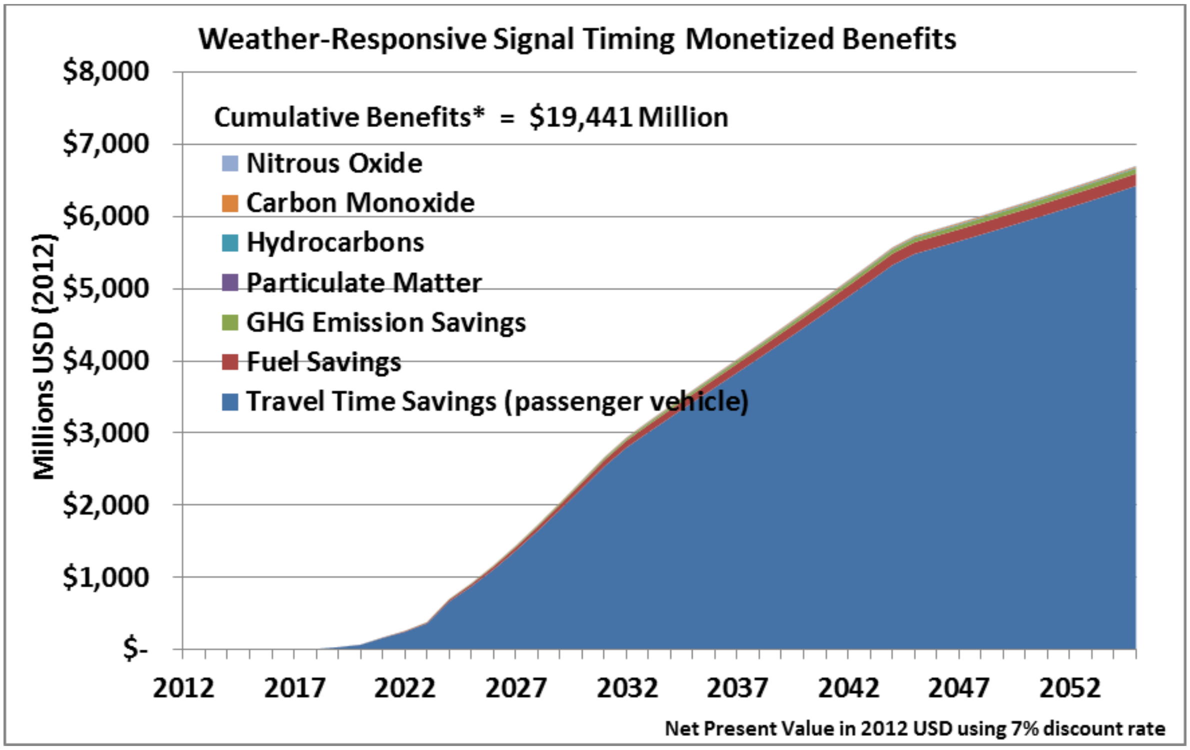
Information and Routing Support for Emergency Responders Results

Non-safety benefits were not estimated for the information and routing support for emergency responders application.

Weather Responsive Signal Timing Results

The weather responsive signal timing application was estimated to have considerable mobility and environmental impacts. The monetized travel time savings, fuel savings, and GHG and criteria pollutant emission reductions benefits are displayed as annual stacked totals for the entire analytical period in Figure 18 below.

Figure 18. Monetized Non-Safety Benefits of Weather Responsive Signal Timing



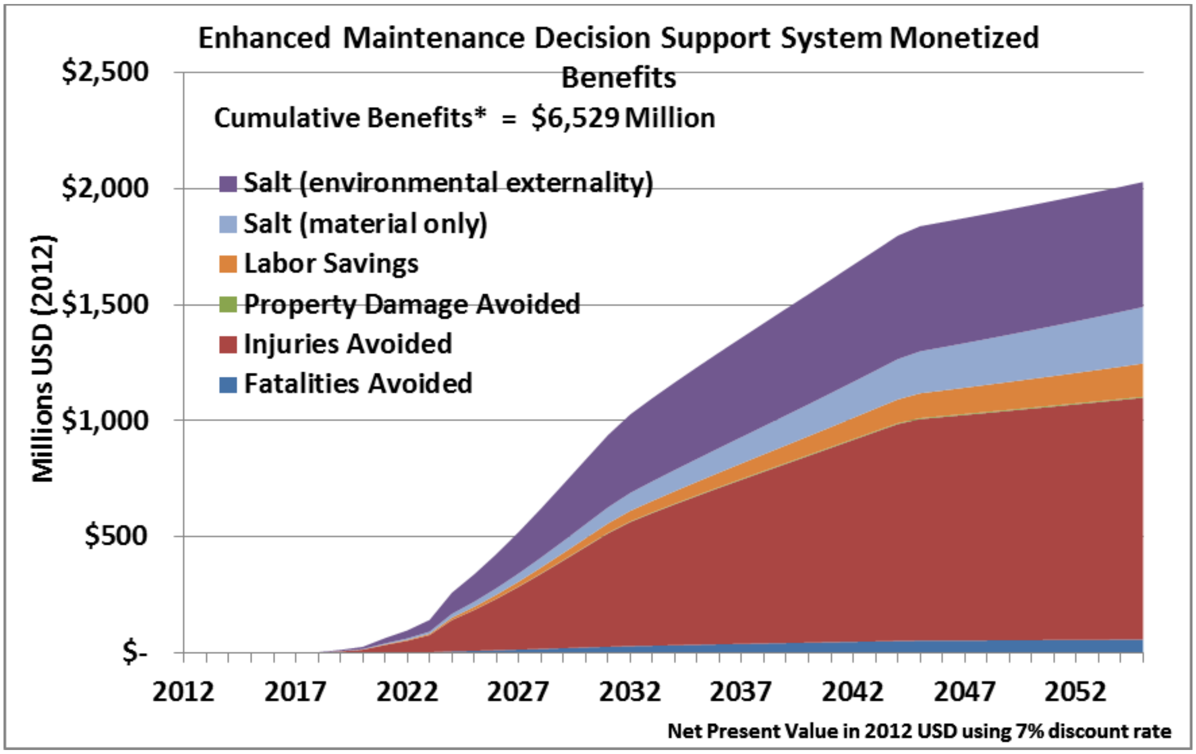
Source: Booz Allen Hamilton, January 2013.

Combined Benefits, Costs, and Net Benefits

Enhanced Maintenance Decision Support System Results

The enhanced maintenance decision support system application was estimated to have considerable safety and non-safety benefits. Figure 19 shows how each of the benefit categories contributes to the monetized benefit total. Injuries avoided is the single largest benefit category and the reduced environmental impacts associated with less salt use is the second largest benefit.

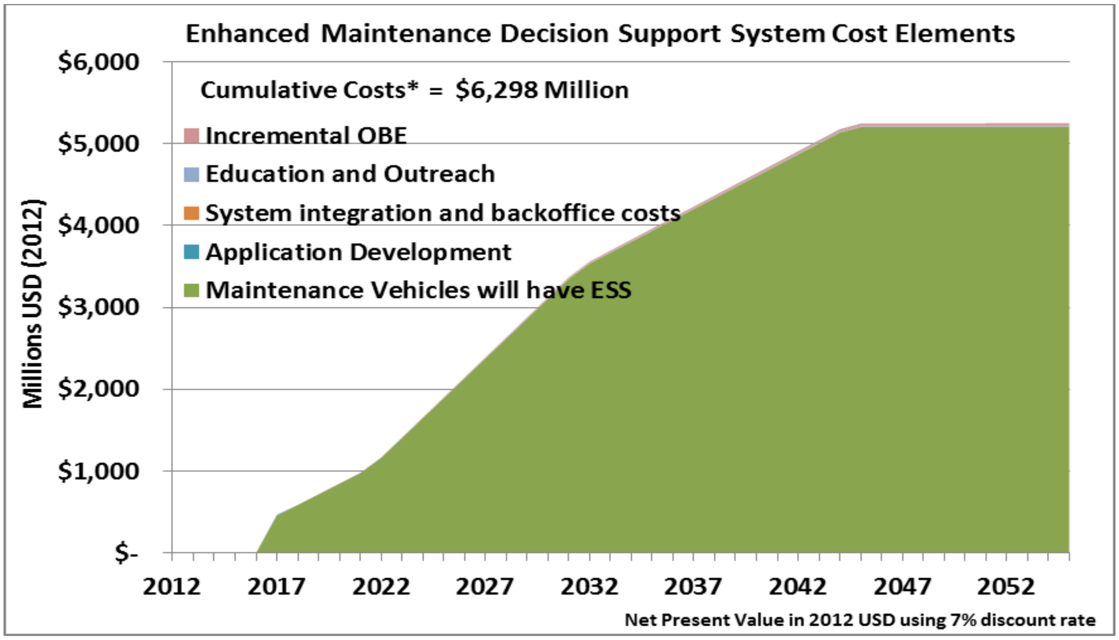
Figure 19. Monetized Safety & Non-Safety Benefits of Enhanced Maintenance Decision Support



Source: Booz Allen Hamilton, January 2013.

The application specific cost elements are displayed as annual stacked totals in Figure 20. The installation and operations and maintenance of environmental sensors on maintenance vehicles cost elements far outweighs any other cost element associated with this application. This is the only applications that incurs that particular cost element; while other applications may leverage the information this technology provides.

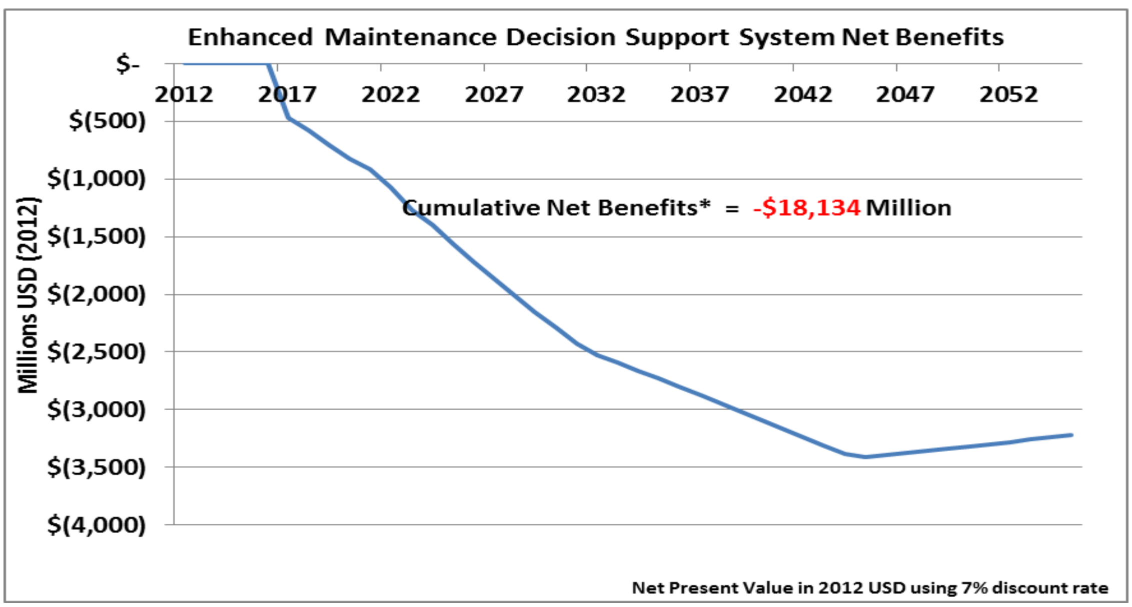
Figure 20. Cost Elements of Enhanced Maintenance Decision Support System



Source: Booz Allen Hamilton, January 2013.

Figure 21 shows the net benefits which considers both the safety and non-safety benefits minus the costs of the application. Due to the high costs of snow plow environmental sensors, the costs for this application are never offset by the benefits. The net present value of the application for the entire 40 years if negative $18 billion.

Figure 21. Net Benefits of Enhanced Maintenance Decision Support System



Source: Booz Allen Hamilton, January 2013.

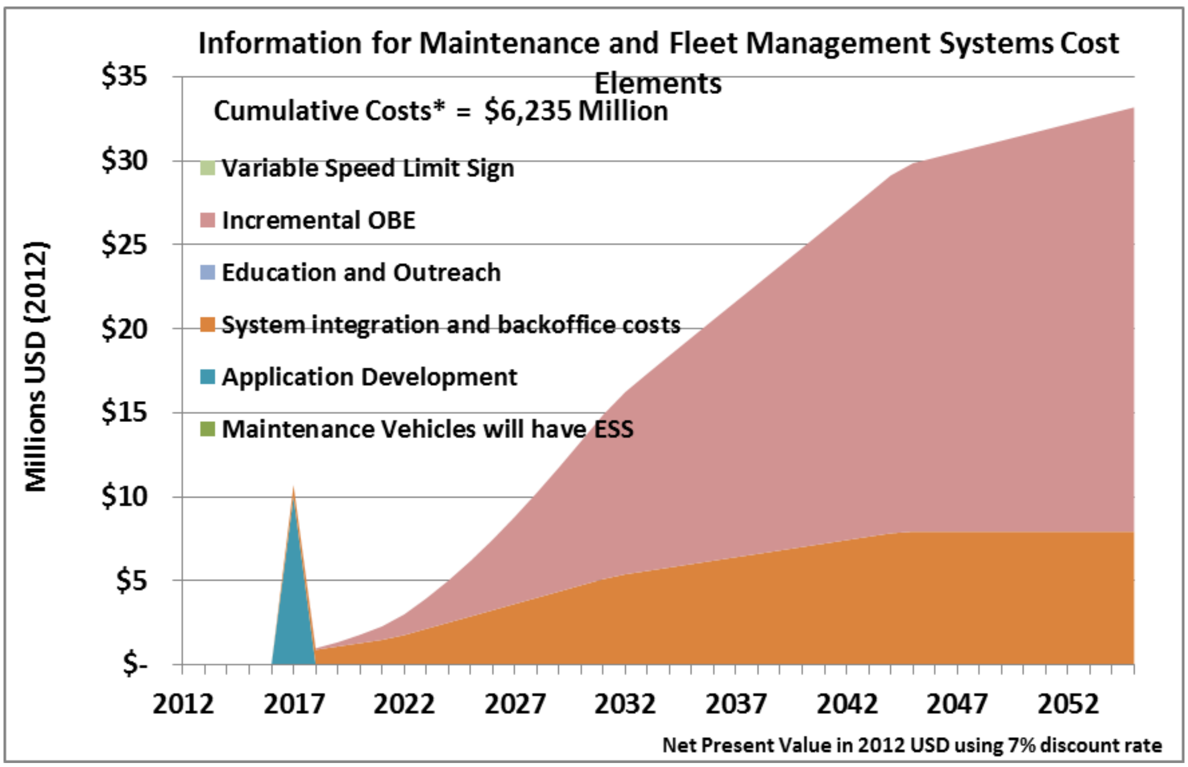
Information for Maintenance and Fleet Management Systems Results

The information for maintenance and fleet management systems application is not intended to yield safety benefits and while non-safety benefits such as operational cost savings are expected, they could not be estimated at this time. The costs were estimated. Figure 22 below illustrates the annual stacked totals of cost elements associated with this application.

The scale of this cost profile is smaller than many of the others and the early capital expenditure of application development is clearly visible. The cost of system integration and backoffice costs and the incremental OBE cost elements are the other two large categorical costs associated with this application. The fully deployed CVE will require an ongoing cost of $32 million for this application nationwide.

The net present value of the costs for this application for the entire period of analysis are $6 billion. The cost savings and other potential benefits that will be evaluated in the Phase II BCA will have to exceed this cost in order for this investment to have a positive return.

Figure 22. Cost Elements of Information for Maintenance and Fleet Management Systems

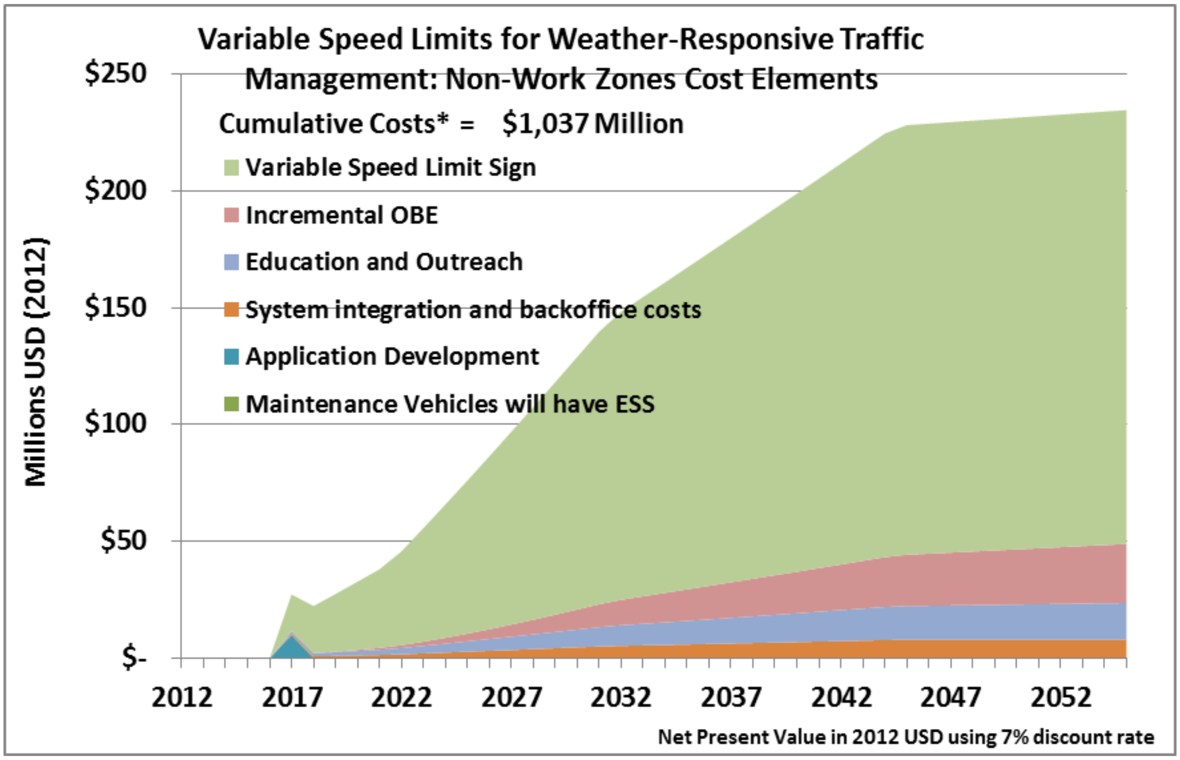


Source: Booz Allen Hamilton, January 2013.

Variable Speed Limits for Weather-Responsive Traffic Management Results

The non-safety benefits were not estimated for this application, therefore only the safety benefits (as described in the previous section) are applicable. All of the costs are attributed to the non-work zone component of the application. Figure 23 below shows the stacked total contribution of the individual cost elements. The application development cost is clearly visible during the initial five year installation period.

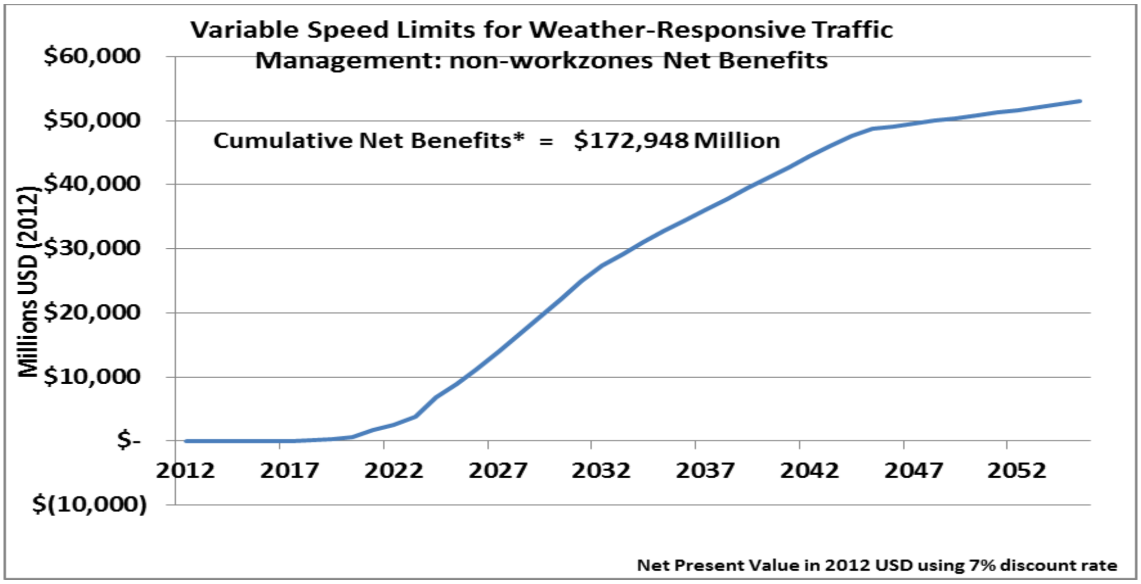
Figure 23. Cost Elements of Variable Speed Limits for Weather Responsive Traffic Management in Non-Work Zones



Source: Booz Allen Hamilton, January 2013.

The safety benefits of the work-zone component of the application will be added to the program total; all of the costs for either work zone or non-work zone are considered here. Figure 24 displays the net benefits of the variable speed limits for weather responsive traffic management in non-work zones. The benefits (safety only) of the application quickly outweigh the costs and yield a total net present value of $173 billion for the entire analytical period.

Figure 24. Net Benefits of Variable Speed Limits for Weather Responsive Traffic Management

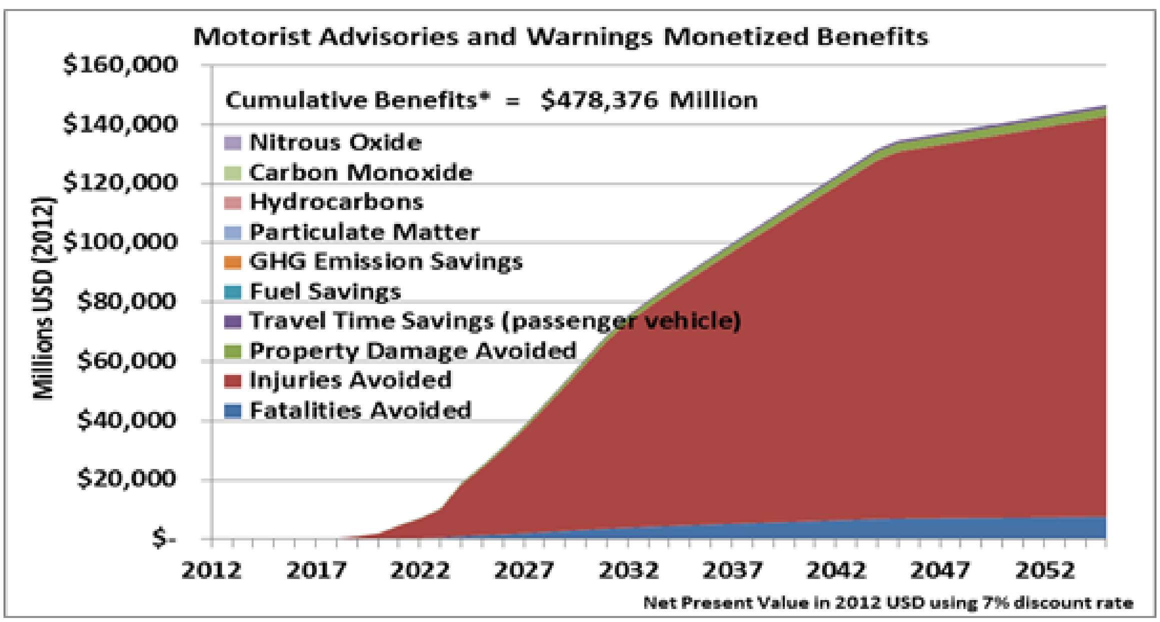


Source: Booz Allen Hamilton, January 2013.

Motorist Advisories and Warnings Results

The motorist advisories and warnings application was estimated to have considerable safety and non-safety benefits. Figure 25 shows how each of the stacked total benefit categories contributes to the monetized benefit total. Injuries avoided is the single largest benefit category, far outweighs any of the other benefit categories.

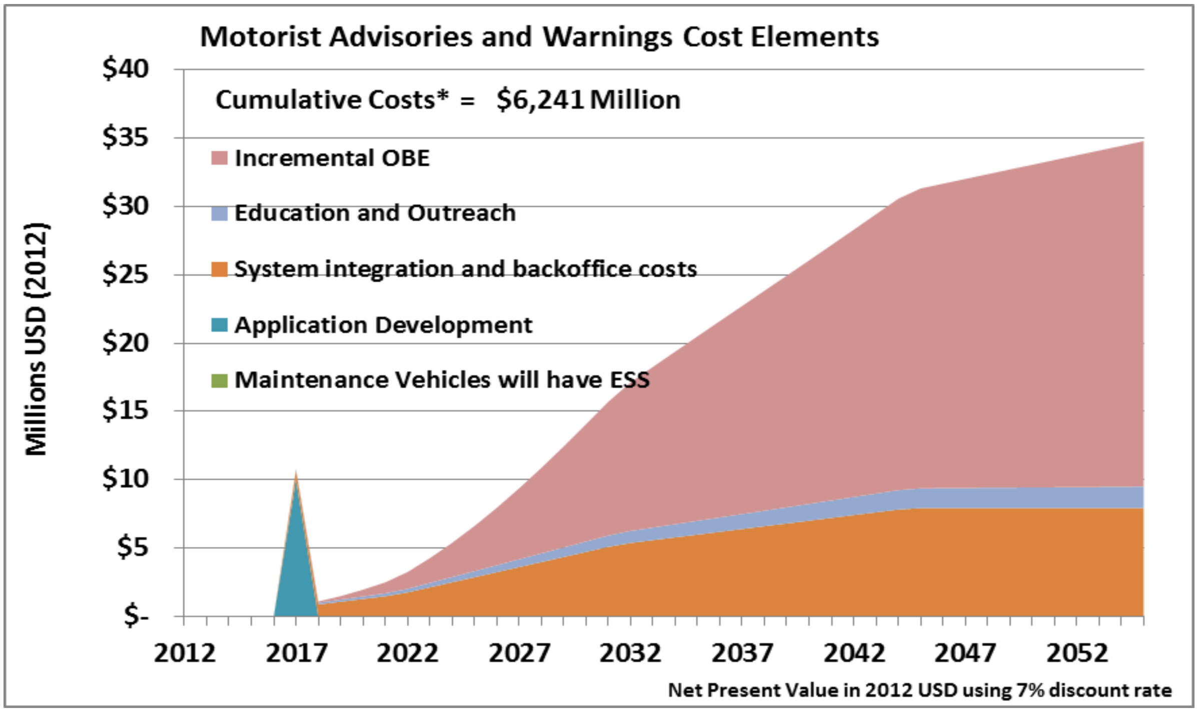
Figure 25. Monetized Safety & Non-Safety Benefits of Enhanced Maintenance Decision Support



Source: Booz Allen Hamilton, January 2013.

The stacked total application specific cost elements are displayed in Figure 26. The installation and operations and maintenance of environmental sensors on maintenance vehicles cost elements far outweighs any other cost element associated with this application. This is the only applications that incurs that particular cost element; while other applications may leverage the information this technology provides.

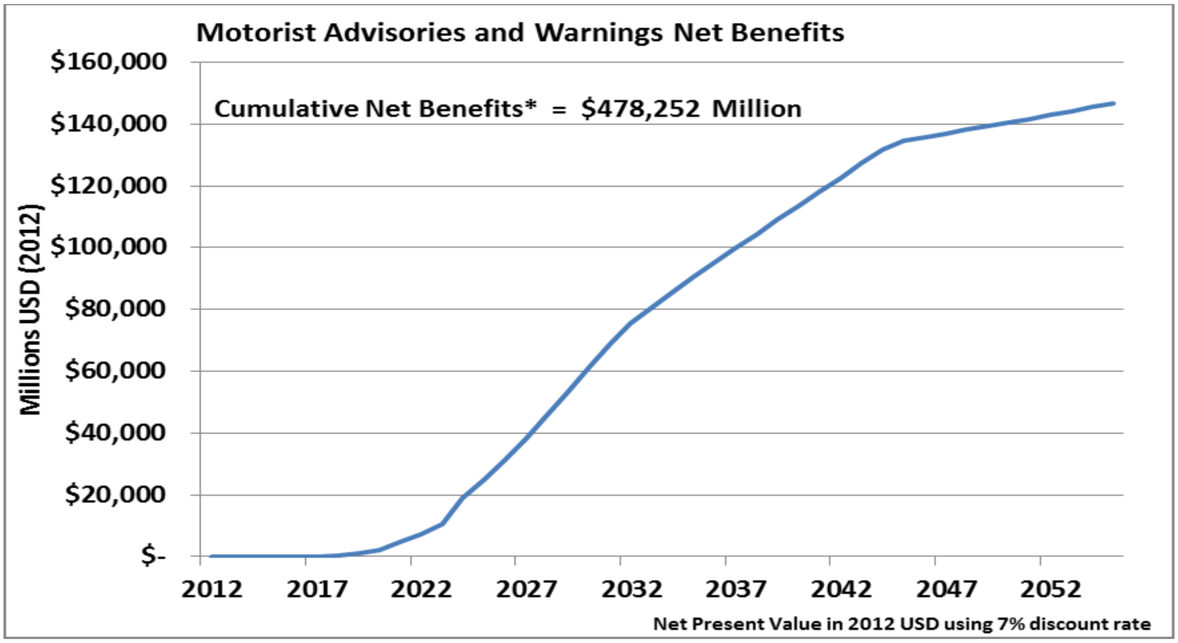
Figure 26. Cost Elements of Motorist Advisories and Warnings



Source: Booz Allen Hamilton, January 2013.

The motorist advisories and warnings has a high rate of incidents for which it is applicable. Based on the deployment scenario, this application yields the highest safety benefits nationwide. Figure 27 below illustrates the net benefits of the application. The application's benefits quickly outpace the costs and the total net present value for the entire analytical period is $478 billion.

Figure 27. Net Benefits of Motorist Advisories and Warnings

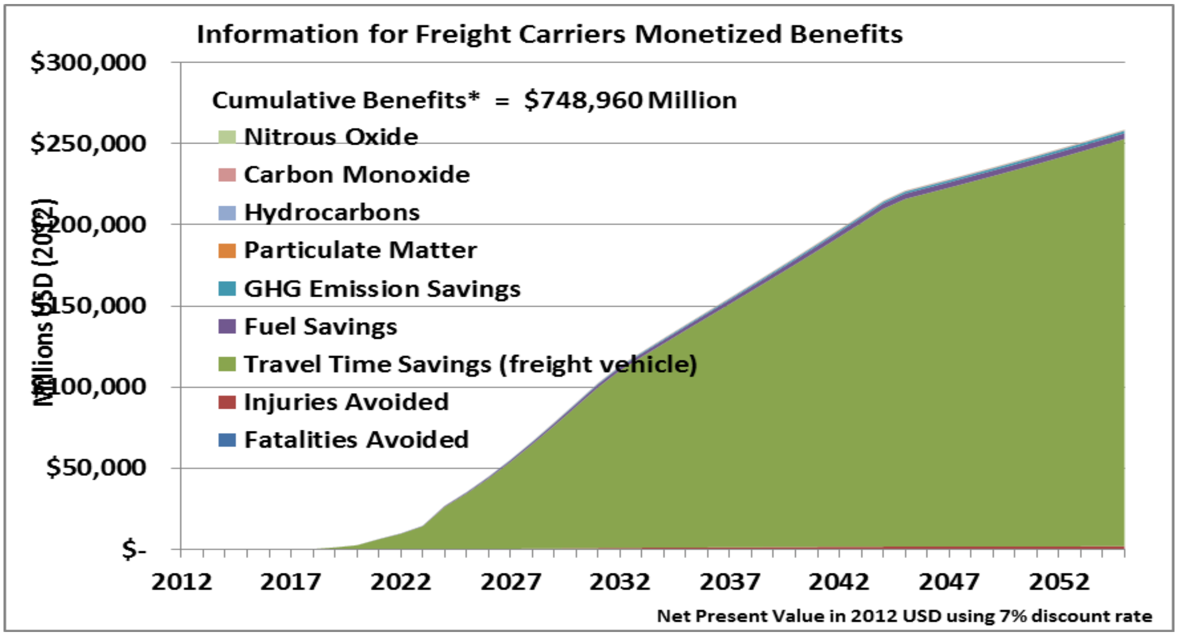


Source: Booz Allen Hamilton, January 2013.

Information for Freight Carriers Results

The information for freight carriers application was estimated to have considerable safety and non-safety benefits. Figure 28 shows how each of the benefit categories contributes to the monetized benefit total. Injuries avoided is the single largest benefit category, far outweighs any of the other benefit categories.

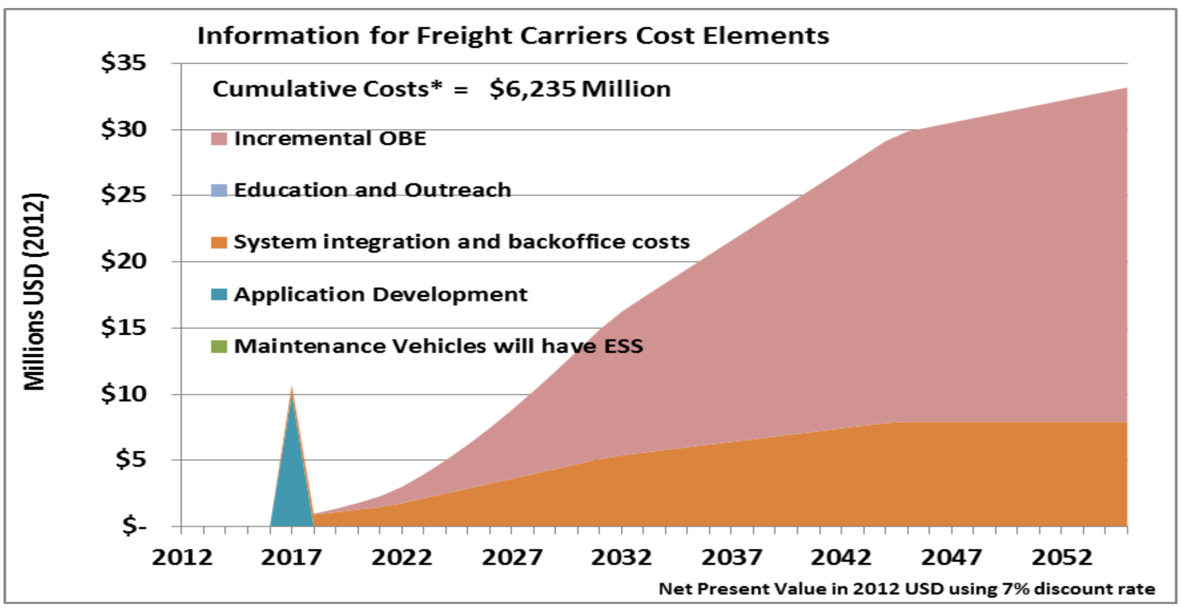
Figure 28. Monetized Safety & Non-Safety Benefits of Information for Freight Carriers



Source: Booz Allen Hamilton, January 2013.

Figure 29 displays the stacked total cost elements associated with the application. The application development cost is clearly demonstrated in the early years; ongoing incremental OBE and system integration and backoffice costs comprise the major cost components.

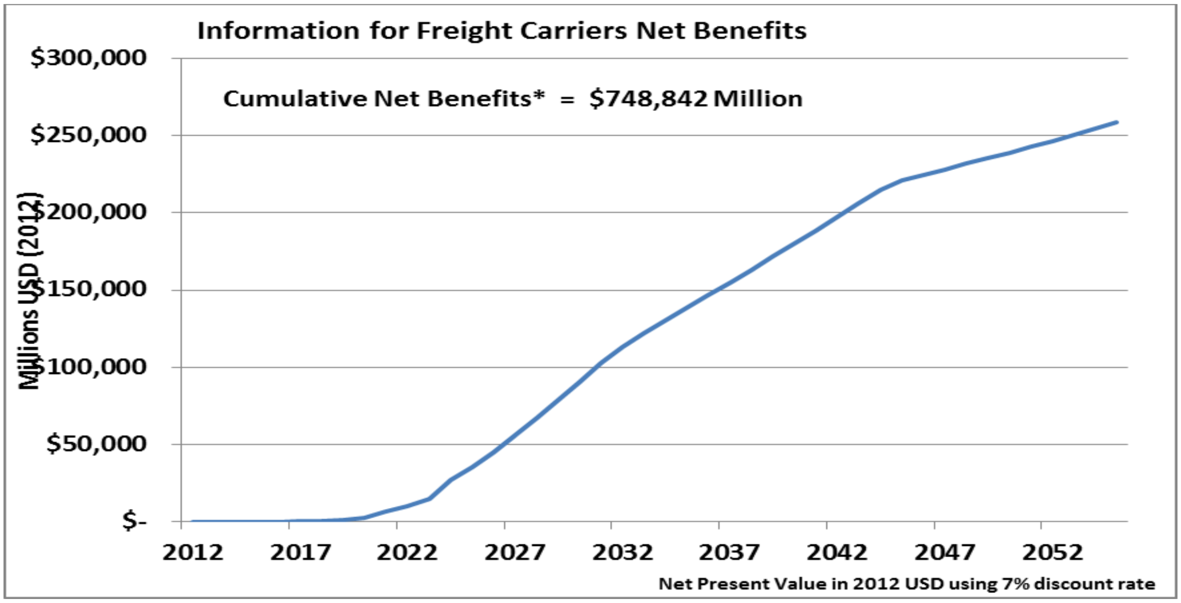
Figure 29. Cost Elements of Information for Freight Carriers



Source: Booz Allen Hamilton, January 2013.

The net benefits for the information for freight carriers application is displayed in Figure 30. The safety benefits of the applications outweigh the costs quickly and yield a positive overall net benefit of $749 billion (net present value for the entire period of analysis).

Figure 30. Net Benefits of Information for Freight Carriers

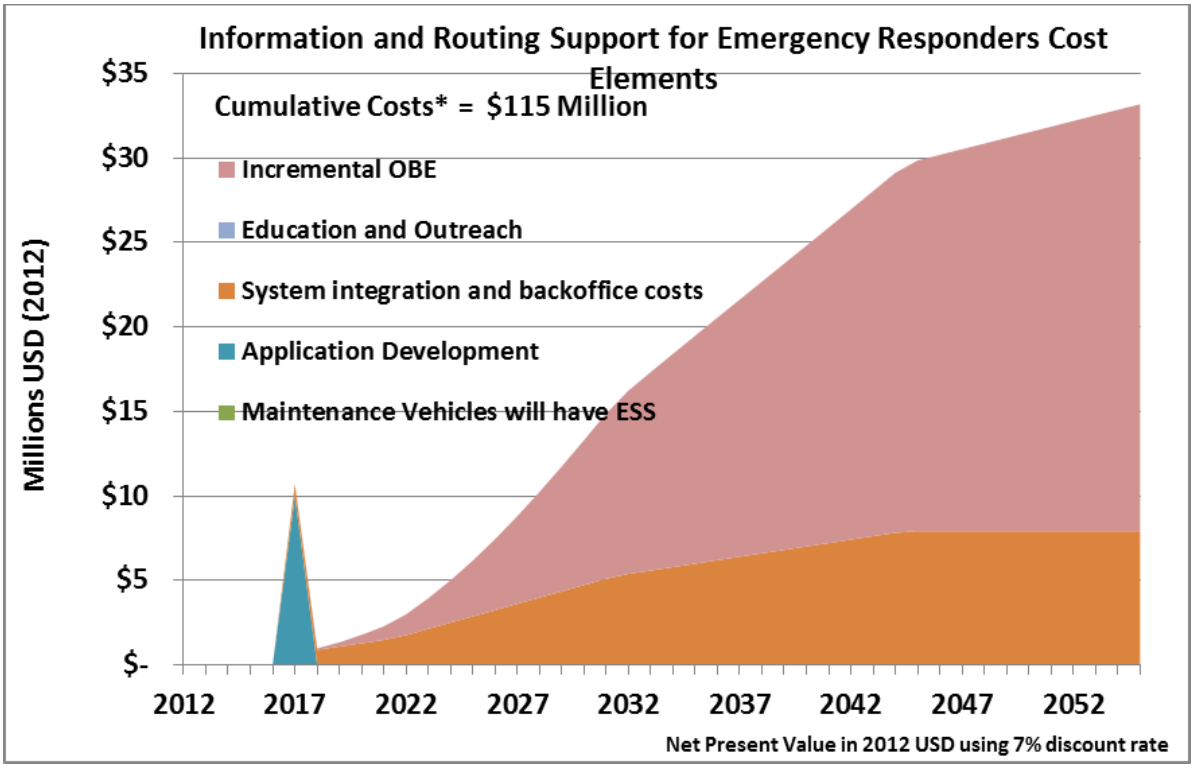


Source: Booz Allen Hamilton, January 2013.

Information and Routing Support for Emergency Responders Results

Figure 31 displays the stacked total cost elements associated with the application. The application development cost is clearly demonstrated in the early years; ongoing incremental OBE and system integration and backoffice costs comprise the major cost components.

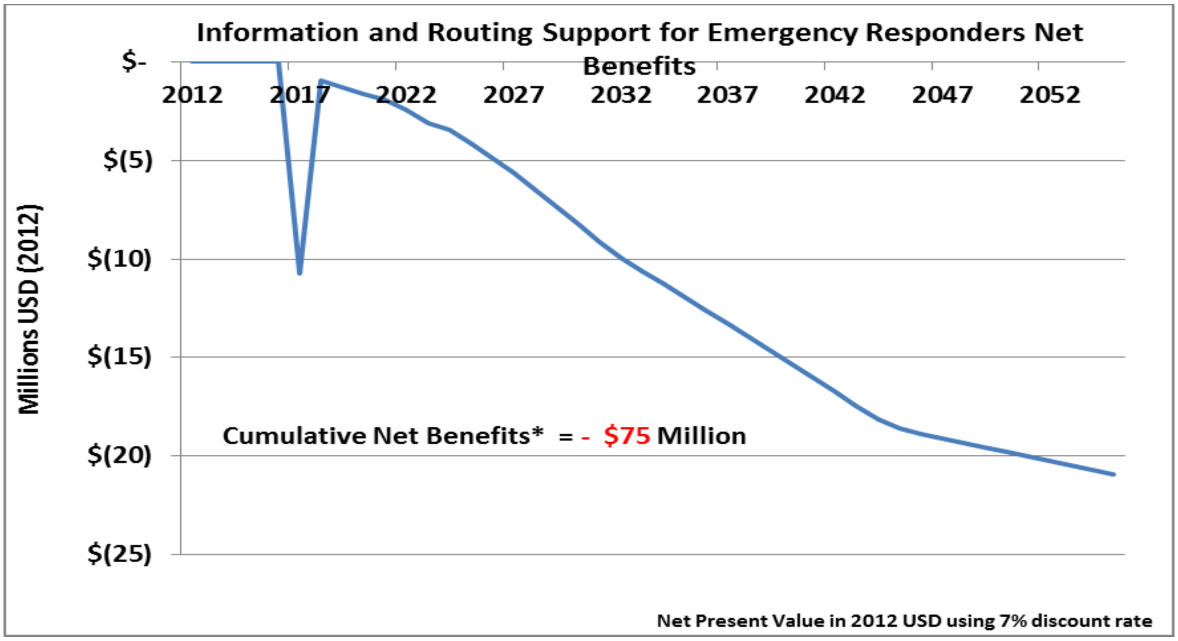
Figure 31. Cost Elements of Information and Routing Support for Emergency Responders



Source: Booz Allen Hamilton, January 2013.

The information and routing support for emergency responders application was not associated with a high number of safety benefits and the benefits never outweigh the costs in the results of the analysis. Non-safety benefits were not evaluated for this application. The net benefits are displayed in Figure 32; the application development cost is clearly demonstrated by a large negative spike early in the profile. The total net present value of the application is negative $75 million.

Figure 32. Net Benefits of Information and Routing Support for Emergency Responders

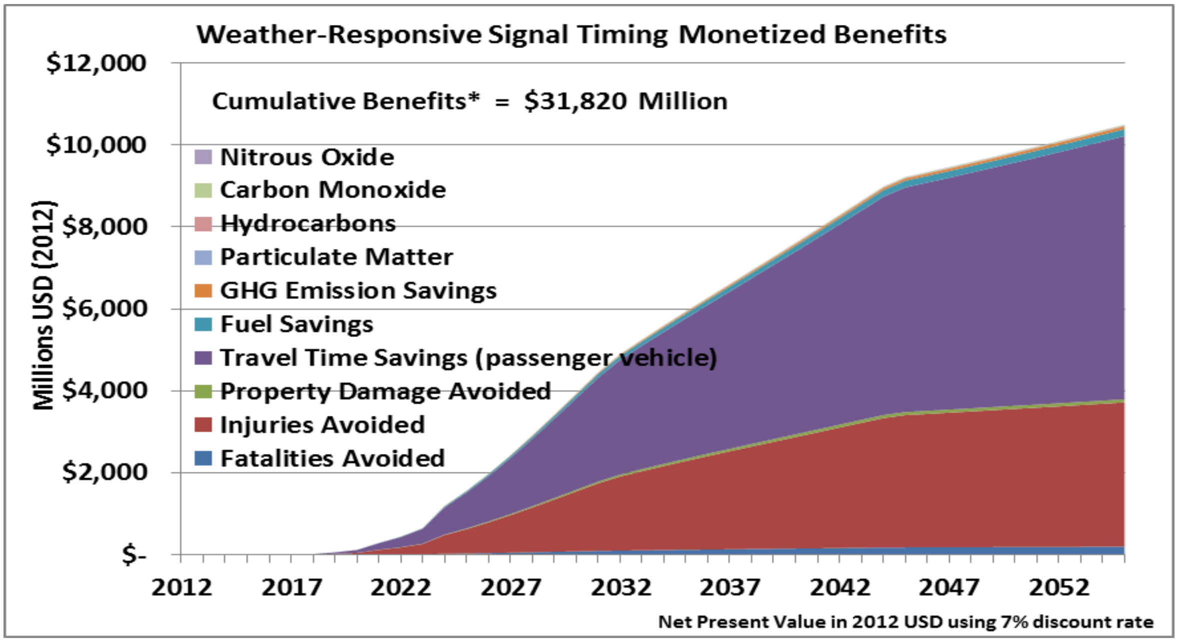


Source: Booz Allen Hamilton, January 2013.

Weather Responsive Signal Timing Results

The weather responsive signal timing application was estimated to have considerable safety and non-safety benefits. Figure 33 shows how each of the benefit categories contributes to the monetized benefit total. Injuries avoided and travel time savings are the most significant benefit categories.

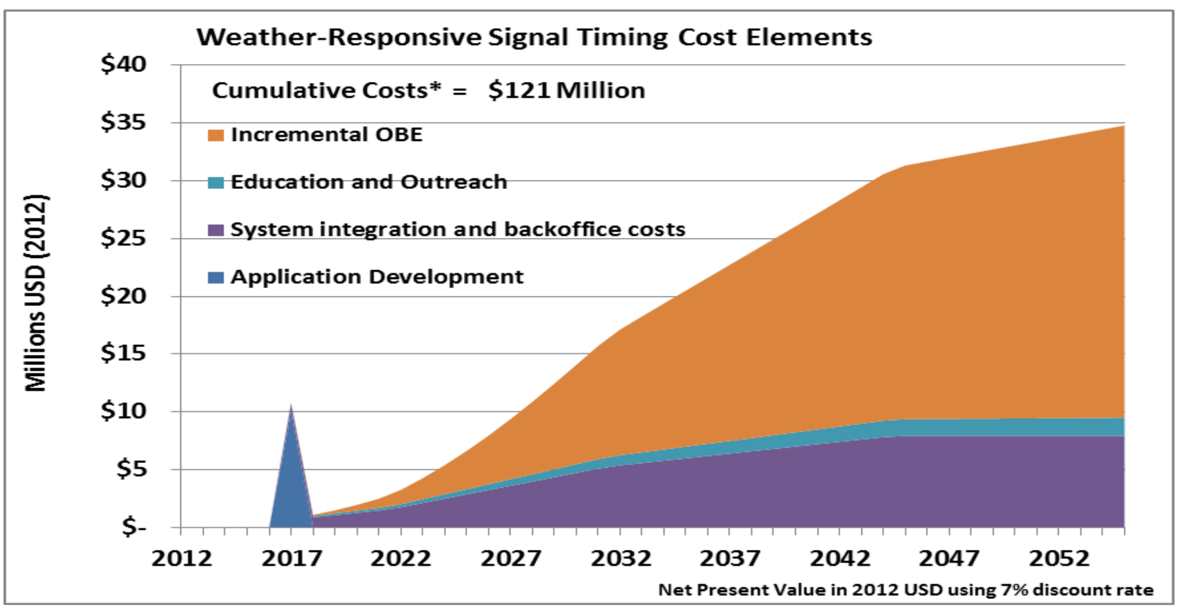
Figure 33. Monetized Safety & Non-Safety Benefits of Information for Freight Carriers



Source: Booz Allen Hamilton, January 2013.

Figure 34 displays the stacked total cost elements associated with the application. The application development cost is clearly demonstrated in the early years; ongoing incremental OBE and system integration and backoffice costs comprise the major cost components.

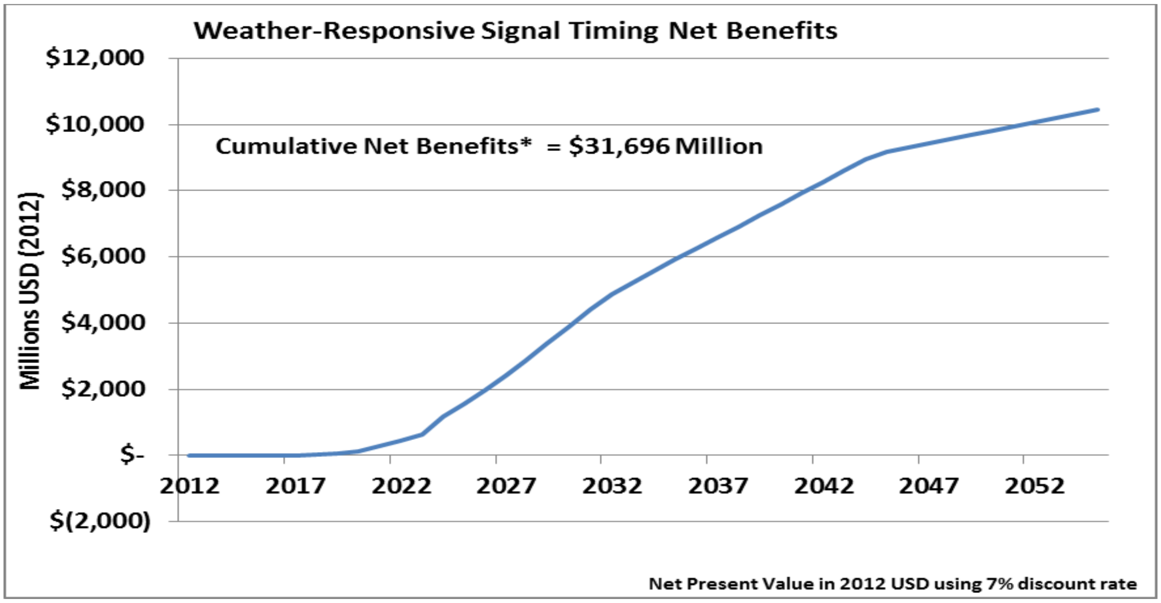
Figure 34. Cost Elements of Weather-Responsive Signal Timing



Source: Booz Allen Hamilton, January 2013.

Figure 35 displays the net benefits of the weather responsive signal timing application. The benefits quickly outweigh the costs in the analysis yielding a positive net benefit. The net present value of the cumulative net benefits is $32 billion.

Figure 35. Net Benefits of Weather-Responsive Signal Timing



Source: Booz Allen Hamilton, January 2013.

Total Program

Table 20 provides the total number of crashes, fatalities, injuries, and property damage avoided by all of the applications for the entire 40-year period.

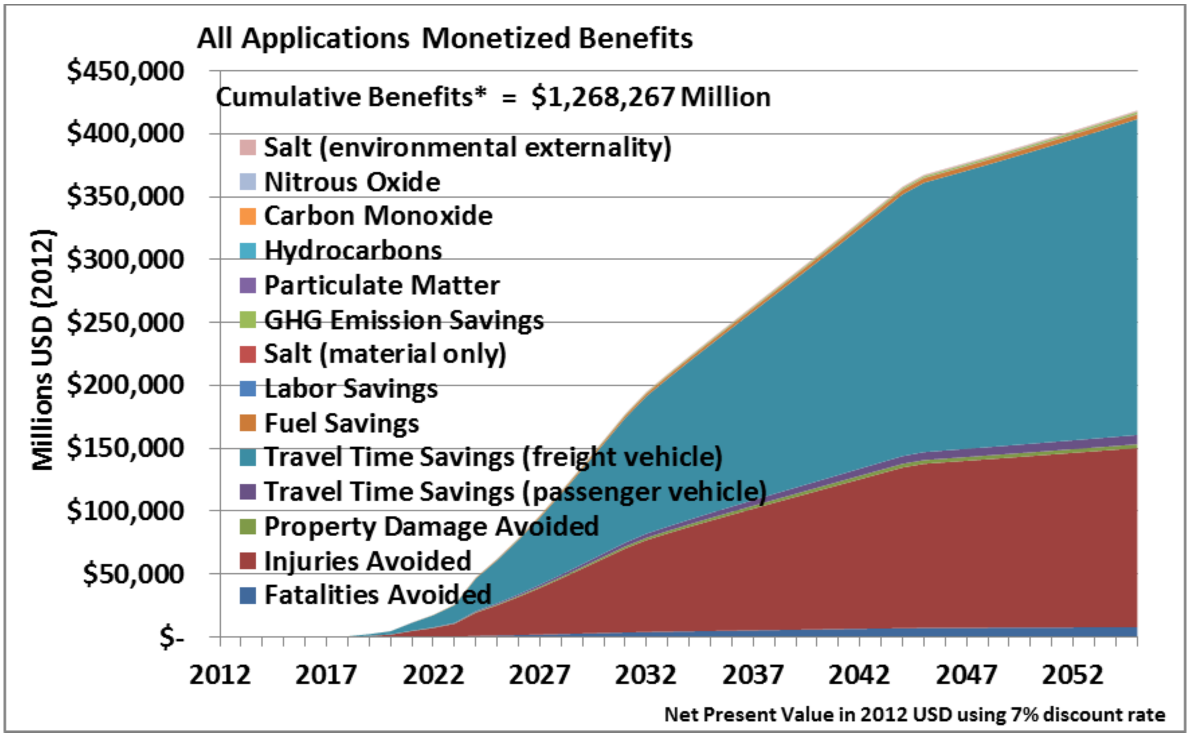
Table 20. Qualitative Safety and Non-Safety Benefits of All Applications

Total Safety Benefits (2012 - 2055)			
Crashes Avoided	Fatalities Avoided	Injuries Avoided	Property Damage Avoided
6,417,482	28,099	2,601,571	$ 15,892,985,409

Source: Booz Allen Hamilton, January 2013.

Figure 36 shows over time how the stacked total monetary value of each of the benefit categories - safety, mobility, operational cost savings, and environmental - contribute to the total monetized estimate of the applications or the total Program benefit. The profile shows that as deployment increases so does the absolute volume and monetary value of benefits. The value of injuries avoided and freight vehicle travel time savings clearly comprise the greatest contribution to the total value of the monetized benefits for all applications.

Figure 36. Monetized Safety and Non-Safety Benefits of All Applications



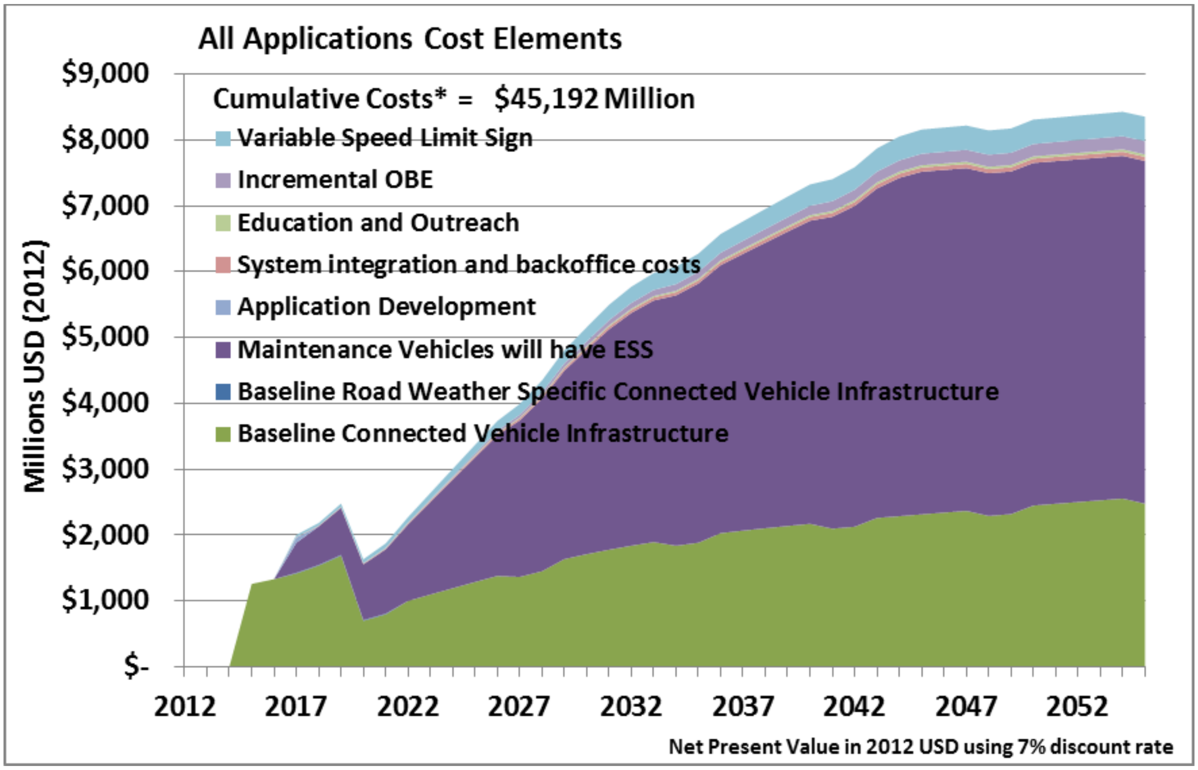
Source: Booz Allen Hamilton, January 2013.

Figure 37 displays the stacked total contribution of each of the cost elements to the total cost for all of the applications. This includes not only the application specific costs, but also the baseline connected vehicle infrastructure costs. These include the installation and operations and maintenance of the RSEs, OBEs, and telecommunication backhaul. The initial installation period of RSEs is clearly demonstrated by the spike in this cost element from 2015 through 2020, after which the costs level out to account for ongoing operations and management of RSEs and the more levelized installation of OBEs which are installed at a slower rate as new vehicles are sold.

The baseline connected vehicle infrastructure is one of the largest cost elements in the analysis of all applications. Baseline road weather specific connected vehicle infrastructure (i.e., the VDT) does not even appear on the graph since it is so small in comparison to the scale of the other costs. A very large cost element is that associated with installation and ongoing operations and maintenance of environmental sensors on maintenance vehicles.

Most of the other cost elements are much smaller and will be incurred over the entire analytical period. The cumulative net present value of all costs is $45 billion; this can be compared to the total cumulative net present value of benefits which $500 billion is yielding a benefit to cost ratio of 11 to 1. In 2055, the fully deployed CVE with all road weather connected vehicle applications will have an ongoing annual cost of $8.3 billion which includes the cost of replacing and integrating new and evolving systems.

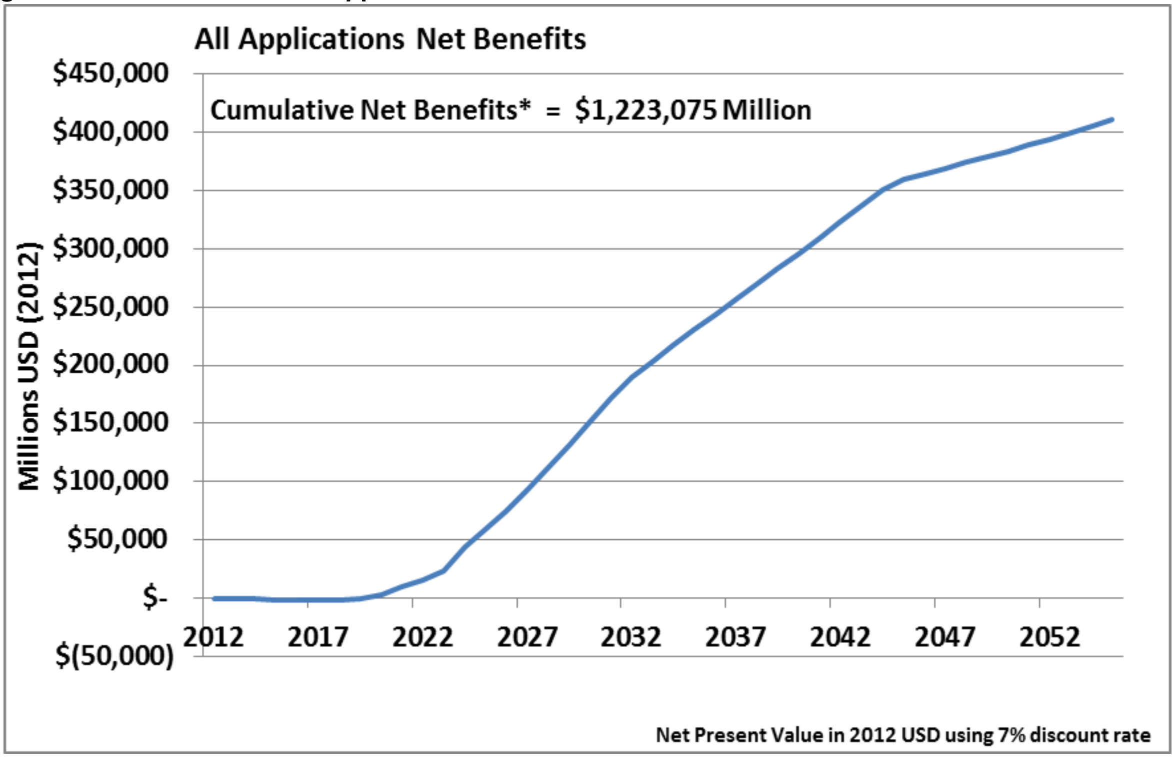
Figure 37. Cost Elements of All Applications



Source: Booz Allen Hamilton, January 2013.

Figure 38 below shows the net benefits (benefits minus costs) that may be realized given the scenario deployment assumptions. The individual applications benefits cannot be directly added (some will likely overlap) and therefore the all applications results include benefits of all of the applications, except Variable Speed Limits for Weather-Responsive Traffic Management in Non-Work Zones because it is expected that these benefits would not be additive to the Motorist Advisories application benefits. All costs are represented including incremental Application Costs, Connected Vehicle System Costs, and Road Weather System Costs.

Figure 38. Net Benefits of All Applications



Source: Booz Allen Hamilton, January 2013.

Comparison of the Applications

The following charts display the seven applications (showing subapplications for the variable speed limits for weather responsive traffic management in work zones in and non-work zones) on one scale for each category so that the safety and non-safety benefits can be compared. Figure 39 is the number of crashes avoided for the life of the analysis. The motorist advisories and warnings application has the highest number of crashes avoided at around 4.4 million. The next most significant application on this graph is the variable speed limits for weather responsive traffic management application.

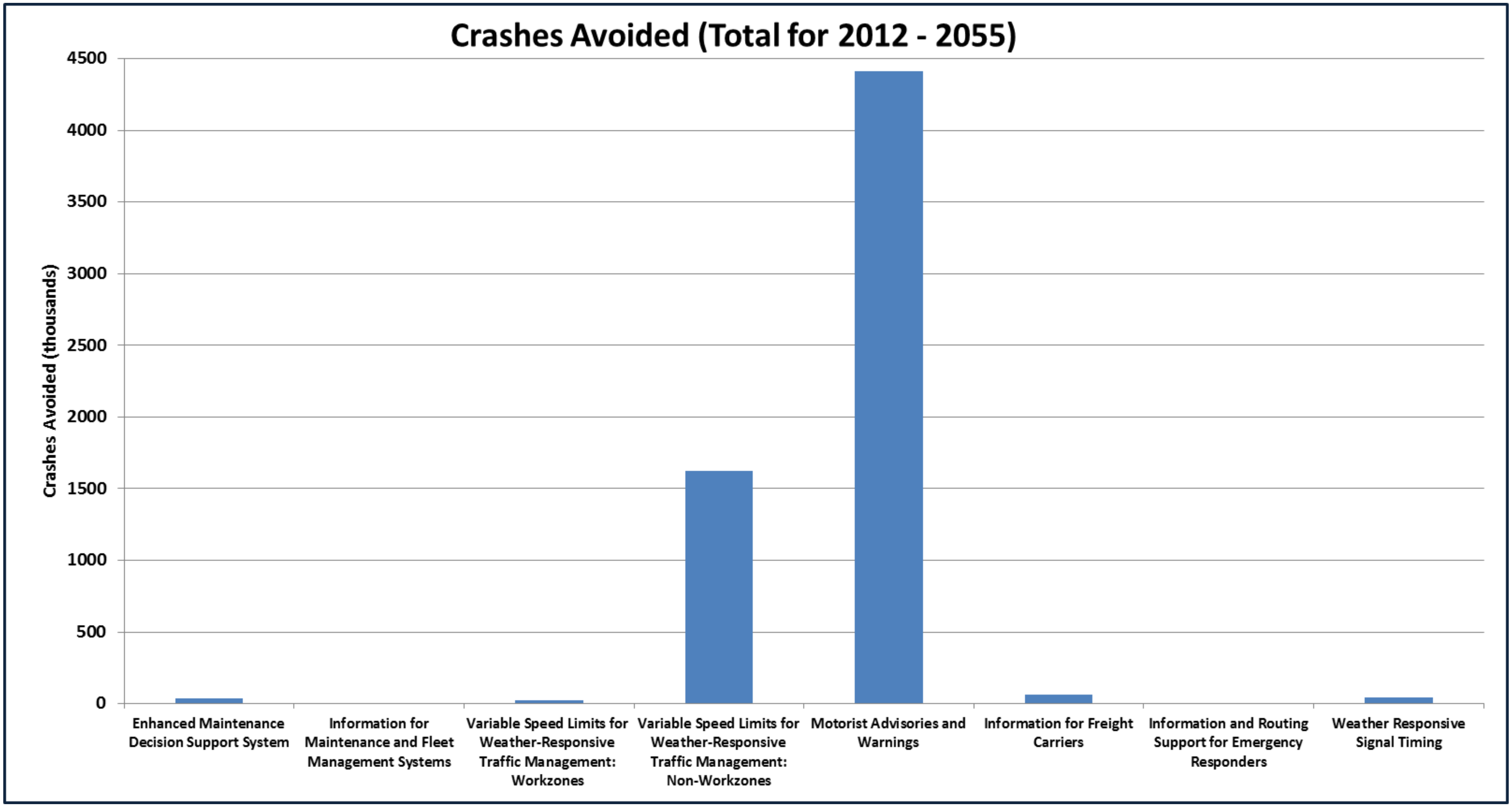
Figure 40 is a comparison of the applications' estimated total number of fatalities avoided. The application ranking will remain the same for each of these comparisons in relative terms; however, the chart provides summary information on the number of lives saved. The motorist advisories and warnings application could potentially save more than 20,000 lives for the 40-year period. Figure 41 similarly displays the number of injuries avoided resulting from each of the applications.

Figure 42 is a comparison of the applications' monetized mobility benefits – including travel time savings for passenger vehicles, travel time savings for freight carriers, and fuel savings. The information for freight carriers application yields by far the greatest mobility benefits of all of the applications; this is predominantly due to the high value of freight travel time savings.

Figure 43 is a comparison of the applications' monetized environmental benefits – including GHG and criteria emission reductions and the environmental benefits of reducing salt use for road treatment. The information for freight carriers application yields the highest environmental benefits, with motoris advisories and warnings yielding high environmental benefits as well. Figure 44 is a comparison of the applications' operational cost savings. The enhanced maintenance decision support system yields the highest operational cost savings including labor and material savings.

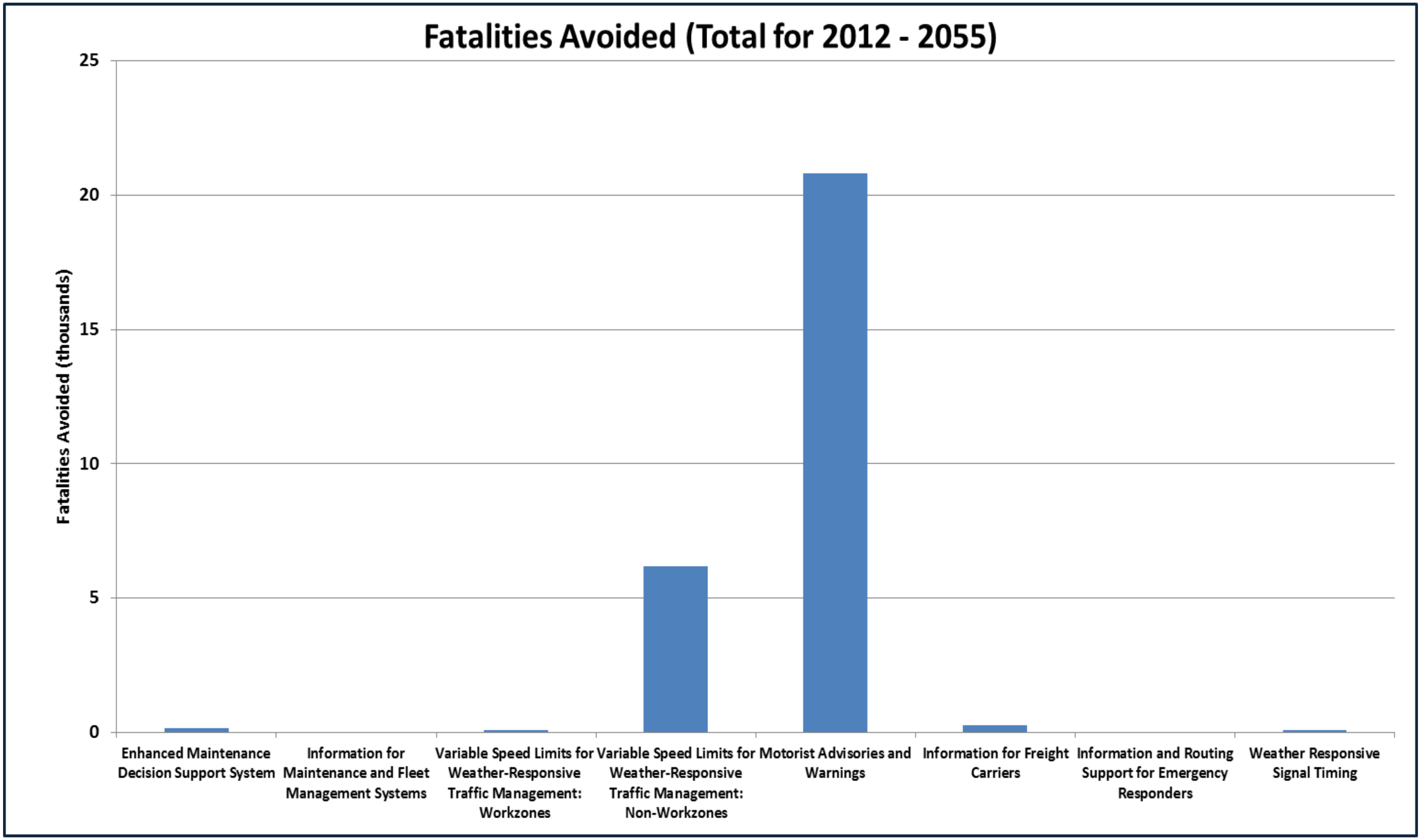
Figure 45 is a comparison of the applications monetized safety and non-safety benefits and costs. In this graphic if the bar is red than the net present value is negative – the costs outweigh the benefits – and if the bar is green than the net present value is positive – the benefits outweigh the costs. The light green represents the non-safety benefits while the dark green represents the safety benefits. Most of the applications earn most of their benefits from safety; while two of the applications have higher non-safety than safety benefits. The sum of the applications chart in the beginning of this section also emphasizes that the safety and non-safety benefits of the road weather applications will far outweigh the costs of the CVE, road weather infrastructure, and application specific costs.

Figure 39. Comparison of Applications' Estimated Crashes Avoided



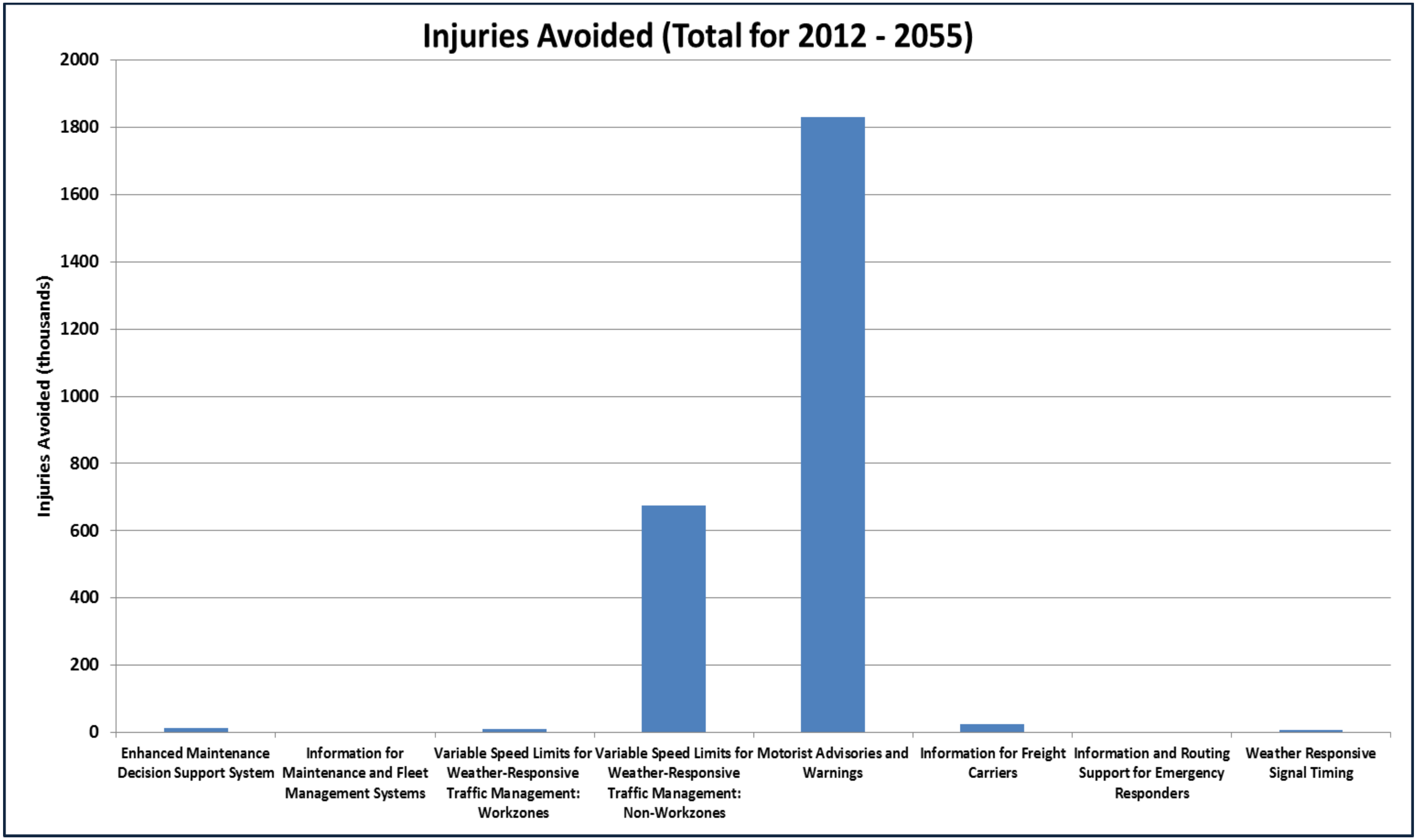
Source: Booz Allen Hamilton, January 2013.

Figure 40. Comparison of Applications' Estimated Fatalities Avoided



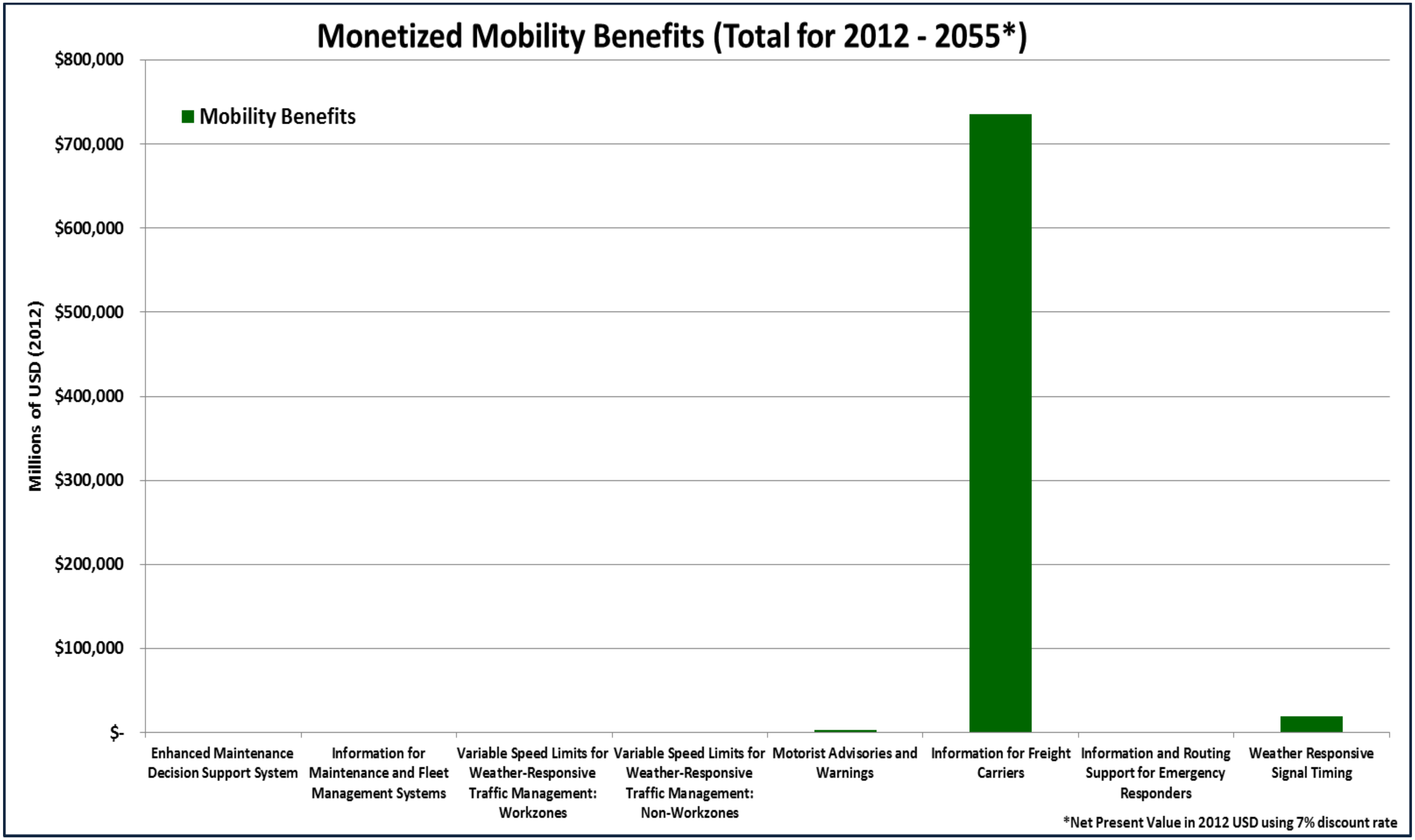
Source: Booz Allen Hamilton, January 2013.

Figure 41. Comparison of Applications' Estimated Injuries Avoided



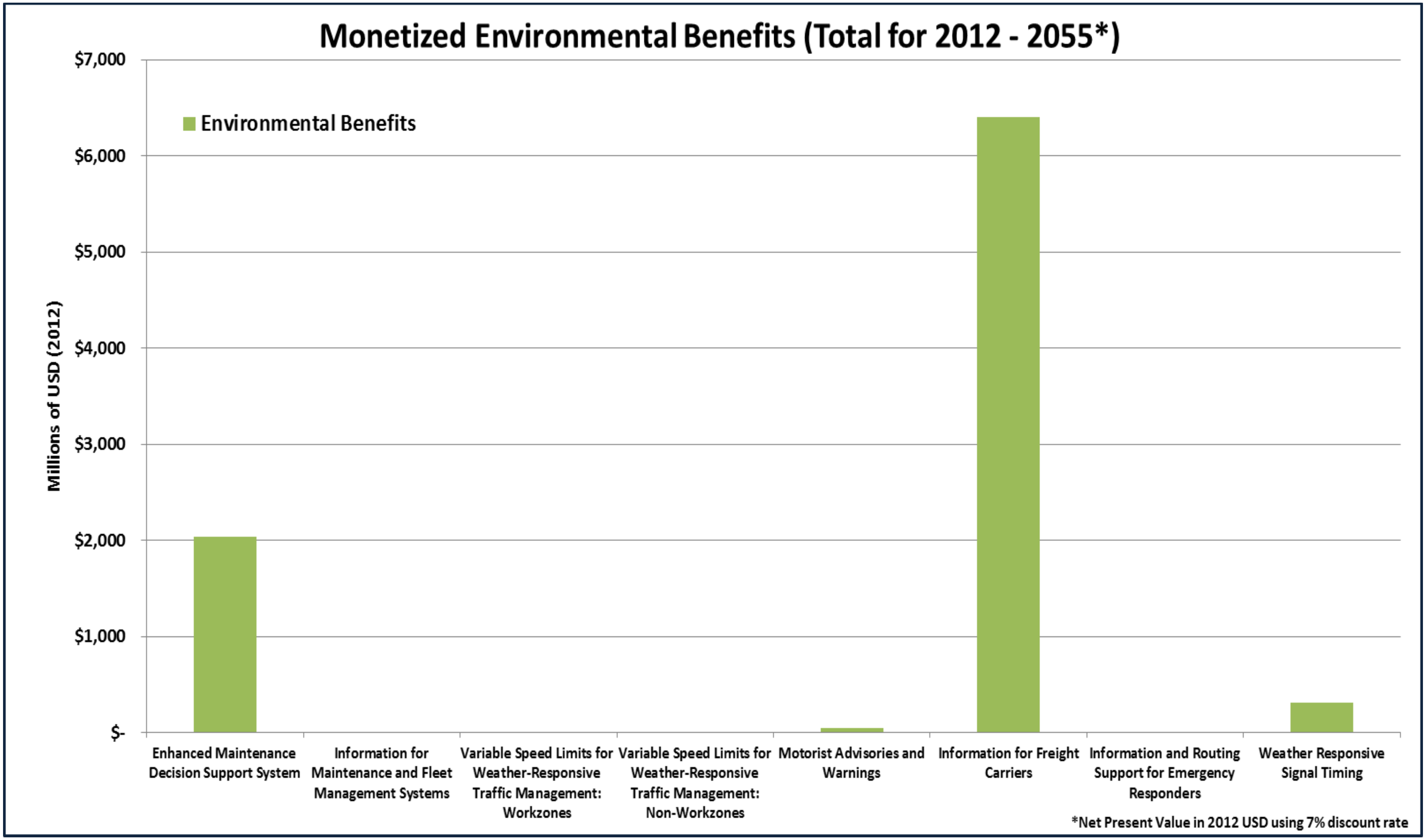
Source: Booz Allen Hamilton, January 2013.

Figure 42. Comparison of Applications' Estimated Mobility Benefits



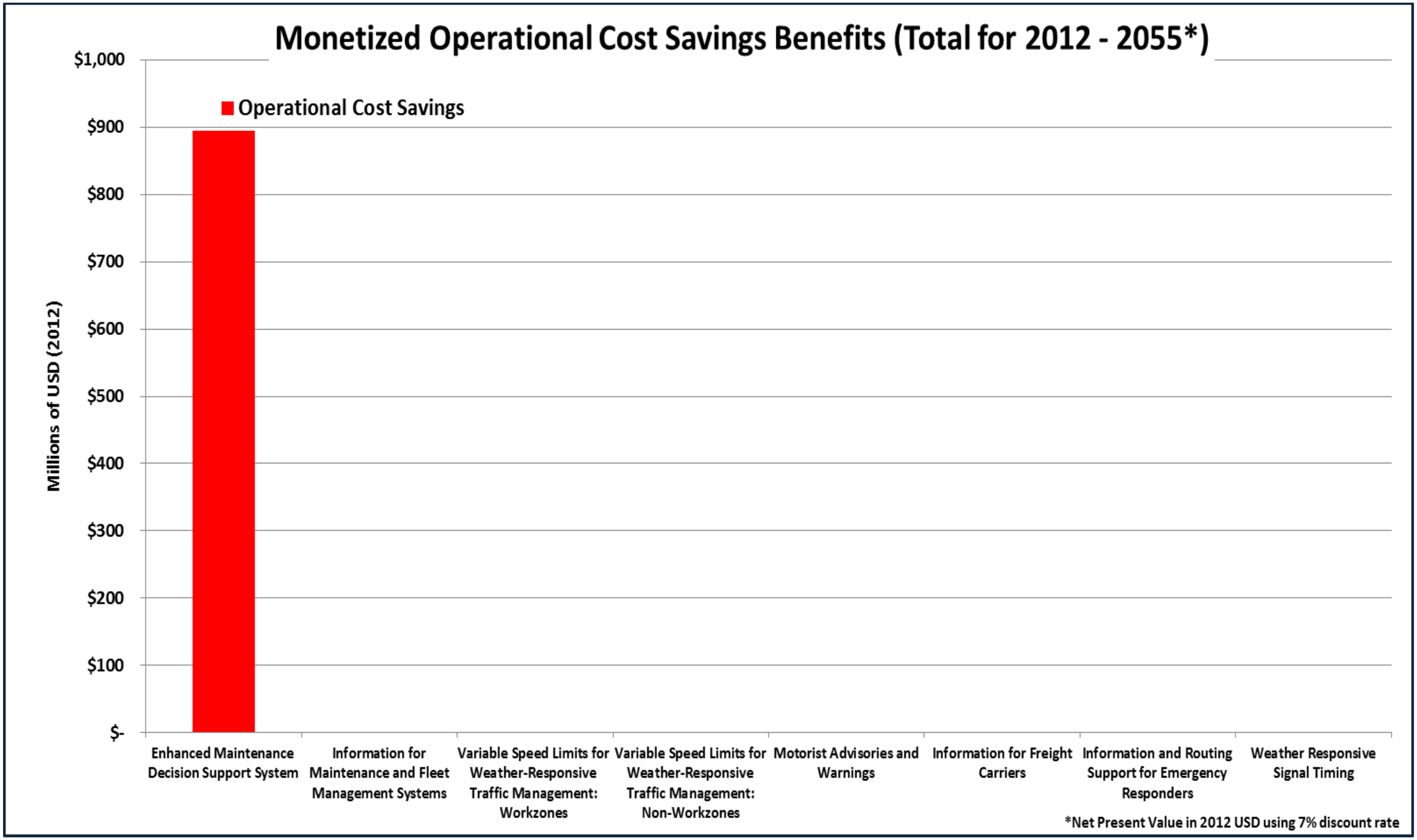
Source: Booz Allen Hamilton, January 2013.

Figure 43. Comparison of Applications' Estimated Environmental Benefits



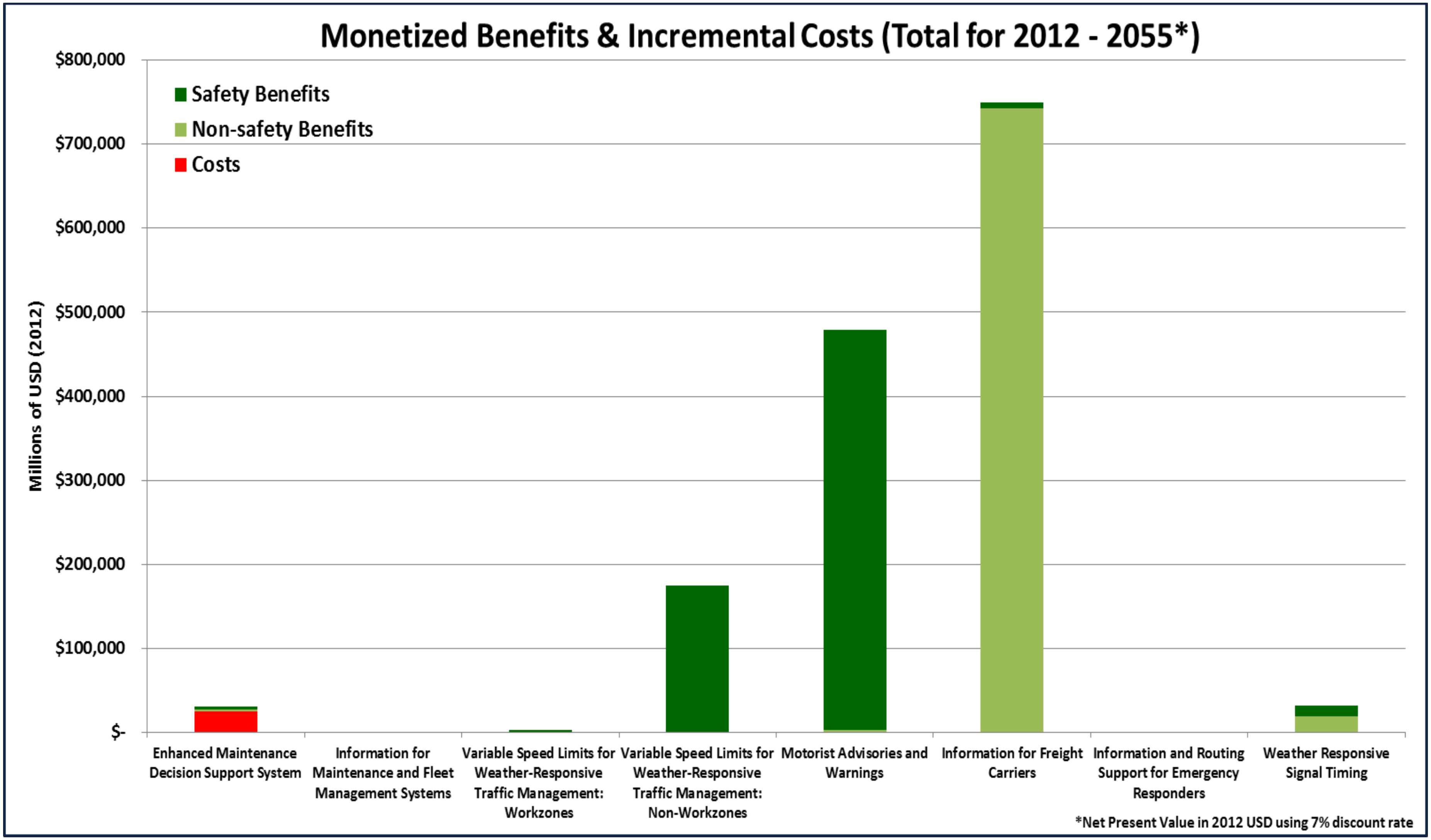
Source: Booz Allen Hamilton, January 2013.

Figure 44. Comparison of Applications' Operational Cost Savings Benefits



Source: Booz Allen Hamilton, January 2013.

Figure 45. Comparison of Applications' Monetized Benefits and Incremental Costs



Source: Booz Allen Hamilton, January 2013.

U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
Federal Highway Administration
Office of Operations, RWMP
1200 New Jersey Ave., SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
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