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Vehicle-Infrastructure Integration (VII) Initiative

Benefit-Cost Analysis

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Executive Summary

The Vehicle-Infrastructure Integration (VII) initiative is an ambitious concept that seeks to bring about substantial improvements in highway safety and trip times via a nationwide, coordinated network of communications between vehicles and the roads they are traveling on, as well as among vehicles themselves. These communication capabilities would be used to exchange safety messages and improve traffic flow.

VII is a federal initiative, with research and planning sponsored by the Department of Transportation's (DOT) Intelligent Transportation Systems Joint Program Office (ITS JPO). It is being pursued as a public-private partnership between the DOT, state and local governments, the automobile manufacturers, and other private entities such as technology and telecommunications providers and consultants.

The deployment of a VII system would entail sizable costs for equipping the roadways and vehicles, and for operating and maintaining the system over a long time horizon. It is estimated that the initial infrastructure will require approximately $5 billion that would be mostly spent in a five year period. Installing VII equipment and systems on all vehicles sold in the U.S. will cost over $1 billion per year at full deployment simply because so many vehicles are involved. A decision to go forward with the VII initiative must consider whether expected benefits – in the form of reductions in crashes and injuries, travel time savings, and environmental and other benefits – justify these costs. Thus, the ITS Joint Program Office commissioned a benefit-cost analysis (BCA) of the VII initiative.

This report summarizes the findings of a second round of benefit-cost analysis and represents an update from a preliminary March 2007 report. Revisions have been made in response to (1) comments received on the 2007 report, (2) information from a benefit-cost Task Force comprised of members of the VII Working Group, (3) information and data obtained from new sources or as a result of a wider scanning effort, and (4) updated guidance from the ITS JPO on program assumptions. This update also reflects the results of a more sophisticated forecast of changes in the vehicle fleet, highway travel, and numbers of crashes, and includes an initial estimate of some of the environmental benefits of VII.

Despite these changes, the underlying BCA methodology is unchanged from the 2007 report. The BCA involves a systematic quantification of costs and benefits of the VII program over its life-cycle. It uses a well-accepted procedure for discounting values in future time periods to present values. The BCA's comparison of the present value of costs and benefits of VII can be used as one component of the planned Viability Assessment for VII.

The benefits of VII stem from the various safety and mobility applications it enables. A set of applications have been identified for consideration in this analysis. A valuation of the expected benefits and costs from these applications has been performed for a 40-year

period. The present value sum of the benefits from eight of the applications is $44.2 billion. About 95% of the benefits result from reduced crashes and the remainder stem from improved mobility and other positive private and societal impacts. Not enough information was available to estimate the benefits of several applications. The Conclusion section discusses some of the other limitations of the benefit calculations.

The present value of the costs of implementing VII, including initial infrastructure costs, on-board vehicle equipment, and all operations and maintenance costs, is $27.3 billion. This estimate is substantially higher than in the 2007 report, due to largely to the effects of additional information on the costs of the roadside equipment and telecommunications backhaul.

Overall, it is estimated that, when looked at from a societal perspective, the VII initiative will generate net benefits of about $16.9 billion. The ratio of benefits to costs is 1.6 to 1. Sensitivity testing was conducted to assess the extent to which the benefit-cost results vary based on different assumptions, inputs, and key parameter values. These tests indicated that the results are robust to the choice of discount rate and time period, but sizable increases to assumed input values for the costs of the onboard equipment can reduce the benefit-cost ratio below 1.0.

The favorable benefit-cost result is but one factor in viability and deployment decisions, but does not imply the initiative will or should definitely be undertaken. In particular, it does not consider whether other alternatives might be more cost-effective or whether it is environmentally acceptable. Nevertheless, it does provide a quantified confirmation that advancing the VII initiative can be expected to have a net positive societal impact.

The results cited for the base case were prepared with only limited information from Proof-of-Concept (POC) testing or application development work. While these results are based on current program assumptions and inputs from knowledgeable persons, as well as reports that were judged to be credible, they will continue to be updated as better information becomes available.

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1 Introduction

Background on the VII Initiative

Intelligent Transportation Systems (ITS) represent the application of advanced technologies, particularly telecommunications, to the field of transportation in order to improve the safety and efficiency of travel. One well-known example is electronic toll collection, whereby motorists can pay roadway tolls using special transponders without the need to stop and pay at a conventional tollbooth.

Despite the progress that has been made with ITS and other transportation initiatives, each year over 42,000 fatalities occur on U.S. roadways and billions of hours are lost to traffic congestion. The Vehicle-Infrastructure Integration (VII) initiative is an ambitious ITS concept that seeks to bring about substantial improvements in safety and trip times via a nationwide, coordinated network of communications between vehicles and the roads they are traveling on, as well as among vehicles themselves.

These communication capabilities would be used to exchange safety messages and improve traffic flow. For example, a vehicle that is braking sharply could send a warning message (wirelessly and instantaneously) to the vehicles behind it, allowing those drivers to take action to avoid a rear-end collision.

VII's communications are based on a protocol called Dedicated Short Range Communications (DSRC), operating at 5.9 gigahertz, a frequency designated for this purpose by the Federal Communications Commission. (Further technical details can be obtained from the VII program.) The VII initiative envisions that at some point in the future, vehicles sold in the U.S. would be equipped with compatible communications equipment – that is, a DSRC radio, along with a Global Positioning System to pinpoint the vehicle's location. Likewise, DSRC units would be installed at regular intervals along the sides of major roadways to provide communications links between vehicles and the roadways.

With this enabling communications infrastructure in place, any number of specific applications could be employed. Since the primary goal of VII is to improve the safety of travel, many of its envisioned uses are safety-related warnings and driver assistance programs. A secondary aim is to reduce delays and congestion, and the associated air pollution and wasted fuel, through applications such as improved traffic signal timing patterns and information for travelers. For transportation agencies, an additional benefit of VII is that it would capture an enormous store of real-time data on traffic volumes, vehicle speeds, and roadway weather conditions, which could be used to improve traffic management, incident management, maintenance, and local transportation planning.

VII is a federal initiative, with research and planning sponsored by the Department of Transportation's ITS Joint Program Office. It is being pursued as a public-private partnership between DOT, state and local governments, the automobile manufacturers, and other private entities such as technology and telecommunications providers and

consultants. At this point, several alternative business models have been proposed for equipping the roadsides and vehicles. This benefit-cost analysis considers costs and benefits as a whole rather than according to the particular entities to which they would accrue.

Purpose of this Report

This report has been sponsored by the ITS Joint Program Office. Its purpose is to provide as comprehensive an accounting as possible of the expected future costs and benefits of VII and its applications. The results of this benefit-cost analysis will serve as a decision-support tool for program managers and policymakers, allowing them to compare the potential net benefits of an investment in VII against those of other potential investments. In particular, this report is designed to provide input to the VII Viability Assessment scheduled for later this spring, with respect to the following criterion: "There is a high level of confidence among government entity members that the benefits, and in particular, the public safety and mobility benefits, sufficiently exceed costs to justify investment in VII." This criterion is just one component of a Viability Assessment that also includes evaluation of technical feasibility, data security, scalability, business model, partnerships, and legal and policy considerations. Each of these evaluations will be based, by necessity, on the information currently available about VII.

Benefit-Cost Analysis

All governments must make decisions about how to allocate limited resources in order to advance the safety, health, and material well-being of their citizens. Benefit-cost analysis (BCA) is an analytical tool that is commonly used to evaluate public-sector investment opportunities. It provides a comprehensive, uniform accounting of costs and benefits across categories and across time periods, thus allowing comparisons of disparate projects.

BCA looks at benefits and costs across the expected lifespan of the project. It is based on the comparison of two scenarios: the state of the world *with* and *without* the project in question. At its core, BCA yields an answer to the following question: Based on what is known now, is this project expected to yield benefits that will exceed its costs, when both benefits and costs are properly monetized and discounted? If the answer is yes, then the project would be considered a "worthwhile" investment and a wise use of public resources, since it would create value to citizens that exceeds its resource costs.

In public-sector contexts, BCA ordinarily takes a "societal" view, counting all costs and benefits regardless of to whom they accrue. As such, it should not be confused with a financial accounting of government expenditures and revenues. For instance, a transportation investment project may allow motorists to save time on their commutes; these time savings would be counted as benefits because they have value to the motorists, even though ordinarily there is no direct revenue to the government. Likewise, BCA

does not address questions of financial viability or business model for public-private partnerships. A project with substantial net societal benefits may, for example, nonetheless be structured in such a way as to be financially unworkable for one or more partners.

Another word of caution is that BCA is *not* an assessment of cost-effectiveness. That is, its results indicate whether a project has net benefits, not whether it is the most effective means to achieve a certain objective or result compared to other approaches or technologies. The analysis does, however, attempt to capture only the *incremental* effects of VII compared to a plausible baseline scenario. For example, analysis of the Ramp Metering application considers not the total mobility benefits from metering, but rather the additional benefits that VII provides compared to current (and projected future) conditions.

One of the key components of BCA is its treatment of costs and benefits that occur in the future. BCA converts these future values into their present-day equivalents, known as *present values*. This is not merely an adjustment for inflation, but an adjustment for the discount rate or "time value of money" and is commonly referred to as "discounting." The basic concept is that any given monetary value is worth less in the future than it is today. As a very basic example, $100 today might be invested in a savings account that would yield $105 next year. Therefore, a promise to pay $105 in one year's time is not valued at $105 today, but just $100 – its equivalent in present value. Because most infrastructure projects take years to complete and continue to offer benefits for many years afterward, it is essential to make these present-value adjustments as part of the BCA. Section II provides more information on this and other BCA topics.

Transportation-related BCAs typically consider several main categories of benefits. The *safety* benefits of a project are expressed in terms of expected reductions in injuries and fatalities on the transportation network resulting from the project in question. These reductions are converted into monetary terms using standardized values. *Mobility* benefits refer to the improved ability of travelers to reach destinations and to reduce the required amount of travel time, for example by reducing congestion delays. Time savings and delay reductions, measured in hours, are converted to dollar terms using standardized values. These values are typically pegged to average wage levels, since wages represent the marketplace trade-off between time and money. *Environmental* benefits stem from reduced vehicle emissions and other pollutants, for example from reductions in vehicle idling time. Again, changes in quantities (e.g. tons of carbon monoxide) are converted into monetary terms using standardized values.

Project Timeline

The BCA effort began in July 2005 with an initial focus on defining the scope of the analysis, highlighting key relationships between variables, and gathering information about the VII program and its potential applications. Interim presentations were given to the VII Working Group in February 2006 and February 2007, and to the VII Executive

Leadership Team in April 2006. These presentations outlined the proposed approach and methodology and identified key parameters, and later provided a summary of interim results. Comments and suggestions from Working Group and Executive Leadership Team members were incorporated, to the extent possible, into a draft BCA report produced in March 2007. This draft report was produced prior to any Proof of Concept (POC) testing of VII, when many details of the program were still to be determined. As such, the report was intended not a definitive accounting of VII but rather as an initial reference point and a springboard for further dialogue and collaboration with the VII community.

To that end, a Task Force composed of Working Group members (including public and private sector representatives), was established to provide a structured forum for feedback on the March 2007 draft BCA report and other relevant information about the costs and benefits of VII and its applications. The Task Force conducted its work through a series of teleconference discussions, focused on the following topics:
- Baseline for analysis and key parameter values
- Mobility applications
- Safety applications
- Private sector applications
- Fiscal impacts
- Equipment and network costs
- Deployment scenarios

Summaries of the Task Force meetings are included in Appendix C.

This updated report reflects the work of the Task Force, comments received from other Working Group members, and changes in USDOT policy guidance. It also includes some analytical refinements and additional information gathered in the interim. Although POC testing has been conducted, specific findings with relevance to the benefit-cost calculations have not yet been made available.

BCA Methodology
Further detail on the benefit-cost methodology is provided in the sections below. At root, however, the approach is fairly simple: the BCA compares the expected *benefits* of the applications that VII will enable against the expected *costs* of VII installation, operations, and maintenance, over a defined project time horizon. The main intermediate steps of this process are as follows:
- Estimate the impacts of VII-enabled applications – for example, the number of hours of traffic delay that would be prevented by a particular traffic signal timing application;
- Convert these impacts into monetary terms using economic variables;
- Estimate the life-cycle costs of VII, including upfront capital costs for equipment installation, ongoing operations and maintenance costs, as well as any incremental costs of specific applications (net of any cost savings that may be produced);

- Forecast the benefit and cost figures into the future across the expected time horizon of the project, with adjustments based on the VII implementation schedule and other factors;
- Translate benefit and cost figures for all future years into present-value terms using a selected base year and discount rate.

Although POC tests have now been conducted, most of the potential VII applications are still in the early stages of development and uncertainties remain about VII's deployment plan and applications. Therefore, the BCA team has developed a flexible, spreadsheet-based model that allows for cost and benefit figures to be periodically updated as new information becomes available. This approach also allows for sensitivity testing, which illustrates the effect of changes in key variables on the ultimate benefit-cost results.

2. Core Variables

"Core variables" is the term used here to refer to economic values and other key parameters that are used in multiple places in the benefit-cost analysis. These variables are not specific to any application or technology, but instead are used primarily to (1) convert impact estimates into monetary terms, (2) to provide appropriate treatment of values that accrue across multiple future years, and/or (3) to scale results to the size of the U.S. road transportation network and light vehicle fleet.

A report[1] produced in the early phases of the BCA effort identified the core variables and recommended values, with information on the rationale for their selection, potential alternatives, and sensitivity cases. This section provides a brief overview of the core variables and identifies cases where the values have subsequently been updated based on policy decisions or input from the Task Force.

Discounting

As mentioned earlier, dollar values in future years must be discounted to present-value terms in order to meaningfully account for the time value of money. The VII BCA uses a discount rate of 7 percent, as recommended by the White House Office of Management and Budget (OMB) in Circular A-94. This is a real, i.e. inflation-adjusted rate, and all BCA calculations are made in inflation-adjusted terms. The base year for present-value calculations is 2008 so that the dollars conform to current values that are familiar to readers at the time this BCA is produced.

Project Time Horizon

The time period over which user and societal benefits and project costs are analyzed for the purpose of BCA is 40 years. This time horizon reflects the expected useful life of the VII network, which is essentially a permanent installation, though naturally individual components will require repair or replacement during this period. Because of the long lead time for deployment and the lags associated with the in-vehicle equipment making its way into the fleet, it is important to use a relatively long project time horizon in order to more accurately reflect the future benefits of the project. With a VII "deployment decision" assumed to take place in 2010, the period analyzed here is 2010-2049.

Value of Travel Time

Travel time saved through VII applications is valued in this BCA at $11.20 per person-hour for local travel and $15.60 per person-hour for intercity travel. These values come from policy

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[1] Vehicle-Infrastructure Integration (VII): Values for Core Variables Used in Evaluating the Benefits and Costs of the VII Initiative. USDOT Draft Report, October 2006.

guidance issued by the Office of the Secretary of Transportation[2] and are based on the idea that users of transportation infrastructure are willing to pay a certain amount of money in order to avoid traffic delays. In cases where vehicle occupancy is not known but is needed to calculate person-hours, an average vehicle occupancy rate of 1.63 persons per vehicle is assumed, based on the 2001 National Household Transportation Survey.

Values of Crashes Avoided

The safety benefits of VII applications are generally expressed in terms of crashes avoided and the associated reductions in injuries and fatalities. To translate these figures into monetary terms, this BCA uses the "comprehensive" or "willingness to pay" approach, which reflects the premise that crash reduction benefits are ultimately defined in terms of what society and individuals are willing to pay to reduce, by given magnitudes, the probability of injuries or fatalities. This is in contrast to approaches based only on the direct financial costs of the crash, such as medical expenses and foregone earnings caused by the injuries.

The use of comprehensive costs follows USDOT guidance on this topic. These comprehensive values reflect the societal costs of crashes, including property damage, medical and legal costs, time lost due to the travel delays associated with the crash, and other direct costs, as well as the intangible costs of injuries, such as pain and suffering. At the time of the March 2007 report, the recommended economic value for the prevention of a transportation fatality was $3.2 million.[3] Recently, the figure has been revised to $5.8 million,[4] with a recommended range of sensitivity testing from $3.2 million to $8.4 million. As in the past, non-fatal injuries are valued according to their severity using the Abbreviated Injury Scale (AIS) and fractional values that are pegged to the fatality figure. These fractions range from 0.20 percent of the fatality value for a "minor" injury (AIS-1) to 76.25 percent for a "critical" injury (AIS-5), and have not yet changed as a result of the recent USDOT update.

Vehicle Fleet and Sales

According to the data from R.L. Polk, the number of light-duty vehicles in use in the U.S. in 2006 was about 232 million. Growth of the light vehicle fleet, including VII equipped vehicles, is being projected by modeling the turnover of the fleet. This model incorporates new light vehicle sales forecast data, obtained from the Energy Information Administration (EIA). According to the EIA, around 16 million light vehicles were sold in 2006 and this gradually increases to around 20 million in 2030. Conditional scrappage rates, derived from R.L. Polk data, are used to provide a measure of the probability associated with vehicles of a given age surviving to the subsequent year. Using these data the total light vehicle fleet and its age

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[2] Emil H. Frankel, "Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis," USDOT-Office of the Secretary of Transportation, February 11, 2003.
[3] "Revision of Departmental Guidance on Treatment of the Value of Life and Injuries," USDOT, Office of the Assistant Secretary for Transportation Policy.
[4] "Treatment of the Economic Value of a Statistical Life in Departmental Analyses," USDOT, Office of the Assistant Secretary for Transportation Policy, February 5, 2008.

composition are forecasted through 2055. Next an estimate of vehicle miles traveled by the entire fleet and VII equipped vehicles is forecasted using average vehicles miles traveled by age of vehicle. A more complete discussion of the creation of a VII fleet and VMT forecasting model is presented in Section 3.

Fuel and Vehicle Operating Costs

Gasoline costs for future years are based on estimates from the Energy Information Administration, adjusted for inflation. In the BCA, net-of-tax prices are used to value any gasoline savings associated with VII applications, since in economic terms the tax component simply represents a transfer from the taxpayer to the government rather than a net benefit (or cost). A value of $2.30 per gallon is used for any projected fuel savings.

Emissions

Vehicle emissions reduced or avoided as a result of VII applications are monetized according to standardized value ranges set by OMB and the Environmental Protection Agency. Current emissions of nitrogen oxides (NOx) by light vehicle are estimated at 8.25 million short tons, with potential reductions in emissions valued in a range from $1,500 to $9,500 per ton. Particulate matter (PM) emissions are assumed to be 220,000 short tons, with valuations ranging between $10,000 and $108,000 per ton. Valuation of hydrocarbons is estimated at $650 to $2,900 per ton. Valuation of sulfur dioxide is estimated at $2,260 to $15,100 per ton. The volume of carbon monoxide emissions is assumed at 511.2 million short tons and volumes of volatile organic compounds (VOC) at 4.87 million short tons. (These values are presented for reference but have not yet been incorporated into the BCA.)

OMB has not yet established values for avoided emissions of carbon dioxide, the principal greenhouse gas. A value of $2 per metric ton of carbon[5] is used in this report, reflecting the lower end of current prices in "cap and trade" futures markets for carbon emissions and offsets.

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[5] A gallon of gasoline produces 19.564 pounds of carbon dioxide, of which the carbon content is 12/44ths (0.273). There are 2204.6 pounds per metric ton.

3. VII Deployment Scenario and Schedule

As noted above, the VII vision calls for dedicated roadside units to be installed along major roads in the U.S. and for corresponding onboard equipment to be installed in vehicles. VII implementation will take years to accomplish due to the sheer number of roadside and onboard units involved and the need to re-engineer vehicle models. The details of VII implementation – that is, the precise *how* and *when* – are important inputs to this BCA for several reasons. First, the upfront costs of equipment installation are directly related to the number of roadside units and onboard-vehicle units that will be needed. Second, because the benefits of VII's applications can (with some exceptions that are discussed below) only accrue in locations that are equipped and/or in vehicles that are equipped, the timing of the phase-in period strongly influences the benefit calculations. Third, by virtue of the discounting formula used, the specific years in which deployment and phase-in occur will affect the values of future benefits and costs when expressed in present-value terms.

The federal VII program and the VII Working Group are exploring alternative business models and deployment scenarios, and a definitive deployment schedule has not yet been established. For the reasons noted above, some assumptions about deployment dates and phase-in periods are nonetheless needed in order to conduct benefit-cost analysis. This report uses a basic deployment scenario that is based on previous JPO reports[6] and more recent informal guidance from the JPO. It is important to view this information as a set of working assumptions used for analytical purposes rather than policy decisions.

On-Board Equipment Deployment Schedule

In this scenario, VII onboard equipment (OBE) would be installed on *all* new light-duty vehicles produced for the US market, with a four-year phase-in period starting in 2012. That is, approximately one-fourth of *new* vehicles produced in 2012 would have the OBE, then one-half in 2013, three-fourths in 2014, and then all new vehicles in 2015 (see Table 3.1). This transition period is designed to allow automobile manufacturers time to adjust the design and engineering of their vehicle models to accommodate the new equipment. OBE installation on heavy commercial vehicles and public transit vehicles is not assumed in this scenario. It is further assumed that OBE would be standard equipment rather than an option that could be chosen by some vehicle purchasers at an additional cost.

Table 3.1. Assumed Deployment Schedule for VII Equipped Vehicles

	2012	2013	2014	2015 and beyond
Share of <u>new</u> light vehicles with installed VII OBE	25%	50%	75%	100%

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[6] W.S. Jones, "VII Life Cycle Cost Estimate," December 2006, updated April 2007, and "A VII Deployment Scenario," December 2005, USDOT – ITS Joint Program Office.

Note that these assumptions refer only to *new* vehicles. This analysis does not reflect the potential for retro-fitting of older vehicles or for aftermarket equipment. Therefore, previously manufactured vehicles without the OBE will continue to be driven on America's roadways for many years after 2012, and indeed non-equipped vehicles will remain in the fleet until they are finally retired (scrapped) and replaced with new vehicles. Calculations on how long this adjustment period will take are important to the BCA because the impacts of VII in any given year are a function of the prevalence of equipped vehicles at that point. (Generally speaking, non-equipped vehicles cannot derive direct benefits from many VII applications, although there are some exceptions which are discussed in Section 4.)

To account for this adjustment period, the BCA team referred to data on vehicle longevity that are gathered by R.L. Polk's National Vehicle Population Profile. These data indicate the likelihood that a vehicle of a given age will be scrapped during that year. Composition of the current on-road fleet by vehicle age and estimates of average miles traveled by vehicle age were also derived from the R.L. Polk and NHTSA data, drawing on the 2001 National Household Travel Survey .

To create a full model of OBE penetration of the U.S. light vehicle fleet over the project timeframe, a VII VMT forecasting model was developed[7] and combined with the VII program's assumptions about the phase-in of OBE among new vehicles. Starting with a total light vehicle population of approximately 232 million in 2006, the fleet was forecasted through 2055 with an average annual growth rate during this period of 0.9%.   In line with recent sales data, new light vehicle sales were assumed to be 16 million in 2006, with an annual average growth rate of 0.95% through 2030, again based on EIA estimates.

Based on the VII VMT forecast, estimates of the number (and share) of equipped and non-equipped vehicles for each year in the analysis period were developed. As one would expect based on our program assumptions, the number of non-equipped vehicles begins to fall as new vehicles become equipped starting in 2012; the fleet reaches the mid-point around 2021, whereby more than 50% of the vehicles in use are equipped with VII. However, older, non-equipped vehicles remain a part of the fleet for decades and their presence must be considered when making calculations about VII benefits and costs.

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[7] See Appendix 1 for a formal discussion of the VII VMT forecasting model

Chart 3.1: Projected Phase-In of VII Equipped Vehicles in the US Fleet

VII Light Vehicle Fleet Penetration
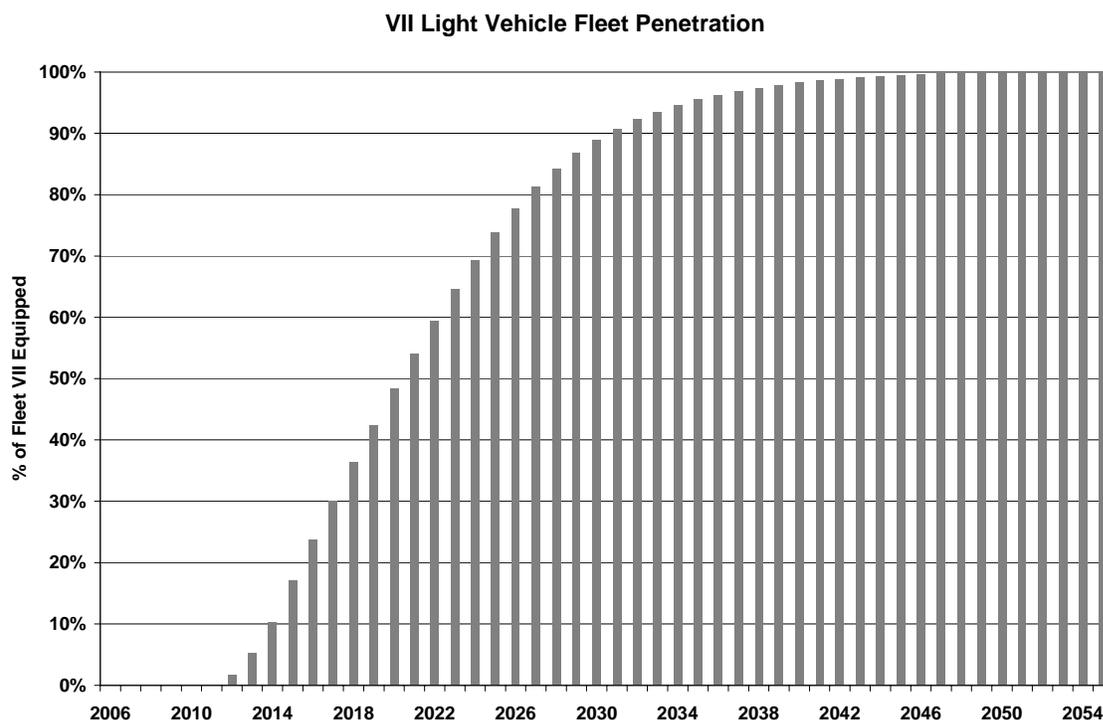
A further refinement that is needed for most calculations of benefits (though generally not for costs) is to look not just at the *number* of equipped and non-equipped vehicles, but the *share of overall vehicle-miles traveled* that they represent. This is because most of VII's safety and mobility benefits will accrue to travelers in proportion to their use of the roadway system, i.e. actual travel, rather than in proportion to mere vehicle ownership. Moreover, it is also true that, for a variety of reasons including comfort and reliability, older vehicles tend to be driven less than newer vehicles. This means that the fleet penetration figures shown above will tend to slightly under-state the actual proportion of miles driven in VII-equipped vehicles, because they do not include any adjustment for differences in VMT by vehicle age.

To account for this disproportionate accrual of benefits, an adjustment to the OBE penetration figures above was made based on VMT per vehicle age within the fleet. Estimates of the average miles driven by vehicle age were derived from R.L. Polk and NHTSA data. As an example of how miles driven changes as a vehicle ages, a new passenger car is driven on average close to 13,700 miles per year, while a 13-year-old passenger car is driven on average about 9,000 miles per year. Data were available for light vehicles up to 36 years old. Based on the VII VMT forecasting model, overall light-vehicle VMT was assumed to grow from a base of 2.7 trillion in 2006 to 6.2 trillion in 2055.

When this VMT adjustment is made, the ramp-up in VII-equipped vehicle miles is slightly more pronounced than when considering vehicle counts alone. The fleet reaches the 50-50 point in terms of miles traveled by equipped and non-equipped vehicles just before 2019, which is around two years before the fleet is more than 50% VII equipped.

Roadside Equipment Deployment Schedule

The assumptions for RSE deployment have been revised to reflect a five-year build-out period from 2011 to 2015. (Previously, deployment was assumed to occur over a four-year period starting in 2009.) This reflects updated guidance from the ITS JPO and is consistent with an assumed VII decision date of 2010.

Several different scenarios have been discussed for the exact phasing of deployment at different types of roadway locations. For example, some Task Force members suggested that urban intersections should be outfitted first, while others suggested the freeway networks should be first. Conceivably, the deployment could also be phased-in according to regional geography or other factors. In the absence of additional information on this point, this BCA assumes that deployment proceeds evenly over the five-year build-out across all location types.

Application Deployment Schedule

The applications reviewed in this report are assumed to be ready for deployment in 2011, with the exception of winter maintenance and traveler information (2012) and signal timing and adjustment (2013). This based on information received from the JPO and discussed via the Task Force. Note that these dates refer to the point at which the application has been developed is technically available, while their actual effectiveness and benefits will depend on factors such as the size of the OBE-equipped fleet. In particular, applications that make use of "probe vehicle" data are assumed to function only once travel from VII-equipped vehicles reaches roughly the 5 percent level.

4. VII System Costs

Using a set of assumptions regarding unit costs, program organization, and deployment scenarios and timelines, a comprehensive model of the total costs to society for developing, implementing and operating the VII program was constructed. All costs are assigned to one of five major cost areas:

- Roadside Infrastructure costs
- On-board Equipment costs
- Network Backhaul costs
- Application-specific costs
- Governance and VII Program costs.

In each of these areas, there are generally three cost types that represent different stages of the program: Development; Deployment or Installation; and Operations & Maintenance. The sum of the discounted stream of these cost estimates is the present value of the cost of the VII program.

In the March 2007 benefit-cost report, the cost estimates relied heavily on two sources: the cost estimates produced by the ITS Program Office[8] and the VII Communications Analysis.[9] After the previous BCA was released, it was suggested that the next iteration take more advantage of ongoing program experience to vet assumptions and fill gaps in the previous costing methodology. As a result, the updated cost estimates incorporate information gleaned from the BCA Task Force as well as cost information published by the California PATH project.[10]

This report's cost estimates differ significantly from those in the 2007 BCA report. The estimated present value in this report is $27.3 billion as compared to the earlier estimate of $16.3 billion. The main reasons for this increase in the estimated cost of VII are an increase in the assumed bandwidth requirements for network backhaul, the incorporation of some previously omitted Roadside Infrastructure equipment costs, and the inclusion of a planned replacement cost for RSEs to reflect their limited lifespan and the need to replace RSE that are damaged in the field.

Roadside Infrastructure Costs

Development
This estimate assumes a development cost of $6 million for Roadside Equipment. This is comprised of three $2 million development grants intended to achieve unit-cost reductions in RSE units. These costs are incurred between the deployment decision and the start of RSE deployment (i.e. during 2010).

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[8] W.S. Jones, "VII Life Cycle Cost Estimate," December 2006, USDOT – ITS Joint Program Office. This BCA makes use of the April 2007 update.
[9] "Vehicle-Infrastructure Integration (VII) Communications Analysis," Version 3.0, Federal Highway Administration, July 2006.
[10] Sharafsaleh, Mohammed et al. "Implementing Vehicle-Infrastructure Integration: Real World Challenges" TRB Paper 08-1377, August 2007.

Deployment

As in the last report, it is assumed there were three main RSE deployment types based on the geographic location of deployment. They were Urban Arterial Traffic Signals, Urban Highways/Freeways/Interstates, and Rural Interstates and NHS routes. Some Task Force members suggested that a fourth category, Urban Arterials without a Signal, be included as well, but as this has not been modeled, as there is no documentation to support a quantity assumption. For this report, this fourth category serves as a place holder, i.e. it is included in the cost tables and underlying computations with zero quantities.

For each of these deployment types, assumptions were made using JPO documentation and Task Force input as to the number within each that might be expected to have access to wireline power and/or communications. In general, urban areas are expected to have access to wireline power in all cases, and access to wireline communications in 20% of the cases. Rural areas are expected to require wireless communication for all RSE, and to need solar power 20% of the time. Estimates were created for the average equipment cost for each installation type, as well as the labor cost and installation equipment rental (e.g. bucket truck).

Equipment costs were compiled from ITS JPO documents,[11] Task Force input, and California PATH experience. The unit costs of the equipment are generally the same as estimated in the March 2007 report, except that the estimate for a solar panel unit has been decreased to $2,000 to reflect information received about the cost of similar units used to power flashing lights in school zones. Based on Task Force input, the cost estimate now also includes several additional pieces of required equipment, called Incidental and Power/Communications Connection costs, that were identified in PATH documentation as being necessary for the roadside equipment. Incidentals might include cabling, weatherproof boxes, and mounting brackets. The table below summarizes the unit costs. Note that VSAT rather than Microwave telecommunications units were assumed for the Rural Interstates/Other NHS areas in order to be consistent with the least-cost analysis for network backhaul.[12]

Table 4.1. Unit Costs Used in Estimating Deployment Costs for Roadside Equipment

Basic RSE Unit	$1,000
RSE Incidentals	$1,000
Signal "Sniffer"	$2,000
WiMax Cost	$1,000
VSAT Unit	$10,000
Connection Cost w/ Wireline Comm.	$1,300
Connection Cost w/ Wireless Comm.	$5,000
Power Connection Cost (wire)	$300
Solar Panel	$2,000
Solar Panel Incidentals	$100

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[11] W.S. Jones, "VII Life Cycle Cost Estimate," April 2007, USDOT – ITS Joint Program Office.

[12] This is a simplifying assumption and should not be construed as a program decision or recommendation.

Again for this iteration, a $2,400 cost of labor is assumed for each major installation component. Major installation components are defined to be a wireless power or communications component (DSRC, WiMax, Solar, etc.). Likewise, all major installations carry a $3,600 installation equipment rental. A summary of the breakdown of RSE distributions and associated costs can be found on the next page, with an overall RSE cost summary in Table 4.3.

Table 4.2: RSE Location-Based Costing Summary

RSE Location		Power/Comm Availability	Equipment Needs	Equipment Unit Costs	Labor Cost	Rental Eq.			Est. # of Sites		
Urban	Arterial Traffic Signal	w/ Wireline Comm	Basic RSE Unit	$1,000	$2,400	$3,600	$11,600	42,000			
			RSE Incidentals	$1,000							
			Signal "Sniffer"	$2,000							
			Comm Connection Equip	$1,300							
			Power Connection Equip	$300					210,000		
		w/o Wireline Comm.	Basic RSE Unit	$1,000	$2,400	$3,600					
			RSE Incidentals	$1,000							
			Signal "Sniffer"	$2,000			$22,300	168,000			
			Power Connection Equip	$300							
			WiMax Unit	$1,000	$2,400	$3,600					
			Comm Connection Equip	$5,000							
	Arterial (No Signal)	Gridline Power and Wireline Comm	Basic RSE Unit	$1,000	$2,400	$3,600	$9,600	0			
			RSE Incidentals	$1,000							
			Comm Connection Equip	$1,300							
			Power Connection Equip	$300							
		Gridline Power, Wireless Comm	Basic RSE Unit	$1,000	$2,400	$3,600					
			RSE Incidentals	$1,000							
			Power Connection Equip	$300			$20,300	0			
			WiMax Unit	$1,000	$2,400	$3,600			0	235,000	
			Comm Connection Equip	$5,000							
		Solar Panel, Wireless Comm	Basic RSE Unit	$1,000	$2,400	$3,600					252,000
			RSE Incidentals	$1,000							
			WiMax Unit	$1,000	$2,400	$3,600					
			Comm Connection Equip	$5,000			$28,100	0			
			Solar Panel	$2,000	$2,400	$3,600					
			Solar Panel Incidentals	$100							
	Highway/Freeway/Interstate	w/ Wireline Comm	Basic RSE Unit	$1,000	$2,400	$3,600	$9,600	5,000			
			RSE Incidentals	$1,000							
			Comm Connection Equip	$1,300							
			Power Connection Equip	$300					25,000		
		w/o Wireline Comm.	Basic RSE Unit	$1,000	$2,400	$3,600					
			RSE Incidentals	$1,000							
			Power Connection Equip	$300			$20,300	20,000			
			WiMax Unit	$1,000	$2,400	$3,600					
			Comm Connection Equip	$5,000							
Rural	Interstate / Other NHS Routes	w/ Powergrid Connection	Basic RSE Unit	$1,000	$2,400	$3,600					
			RSE Incidentals	$1,000							
			Power Connection Equip	$300			$29,300	13,600			
			VSAT Unit	$10,000	$2,400	$3,600					
			Comm Connection Equip	$5,000					17,000	17,000	
		w/o Powergrid Connection	Basic RSE Unit	$1,000	$2,400	$3,600					
			RSE Incidentals	$1,000							
			VSAT Unit	$10,000	$2,400	$3,600					
			Comm Connection Equip	$5,000			$37,100	3,400			
			Solar Panel	$2,000	$2,400	$3,600					
			Solar Panel Incidentals	$100							

Table 4.3: Estimated RSE Deployment Costs (In Millions)

	RSE Deployment Cost	(In Millions)			
	2011	2012	2013	2014	2015
FV	$1,042.4	$1,042.4	$1,042.4	$1,042.4	$1,042.4
PV (2008)	$850.9	$795.3	$743.2	$694.6	$649.2

FV = future value (undiscounted)   PV = present value (discounted at 7%)

Maintenance costs

The March 2007 report assumed a simple maintenance cost factor of 10% annually. This figure was generally well accepted for unplanned replacements – i.e. field losses due to collisions, weather, vandalism, and other factors. However, it was noted by the Task Force that this does not fully account for the cost of continually replacing the roadside equipment at the end of its planned lifespan. As a result, this report includes an assumption of a seven-year useful economic life for these planned replacements.

Summaries for the yearly costs associated with these types of maintenance are below. "Unplanned maintenance" refers to replacement of field losses, and assumes, to be conservative, that the costs of repair or replacement are equal to the costs of initial installation. "Planned maintenance" refers to the replacement of RSE units on a seven-year cycle. Based on Task Force input, the figures assume that some aspects of the replacement and/or repair are less costly than at the initial installation.

Table 4.4: RSE Unplanned Maintenance Costs (In Millions)

	2012	2013	2014	2015	2016	2017	...	2019	...	2029	...	2039	...	2049
FV	$104.2	$208.5	$312.7	$417.0	$521.2	$521.2	-	$471.4	-	$470.6	-	$472.7	-	$479.0
PV (2008)	$79.5	$148.6	$208.4	$259.7	$303.4	$283.5	-	$223.9	-	$113.6	-	$58.0	-	$29.9

Table 4.5: RSE Planned Maintenance Costs (In Millions)

	2019	2020	2021	2022	2023	2024	...	2029	...	2039	...	2049
FV	$173.4	$190.7	$208.1	$225.4	$242.8	$86.7	-	$176.3	-	$169.0	-	$147.0
PV (2008)	$82.4	$84.7	$86.4	$87.4	$88.0	$29.4	-	$42.6	-	$20.8	-	$9.2

On-Board Equipment Costs

Installation
An initial estimate from the VII program was that the basic GPS and DSRC radio components should be available for "well under $50" per vehicle, and a figure of $50 per vehicle was used in the March 2007 BCA report. Some comments received on the March 2007 BCA Report suggested that this estimate may be too low; however, the Task Force raised no concerns that this value was outside of a reasonable range. The $50 per vehicle figure is again used here, but with a sensitivity test showing the effects of alternative values (see Section 6).

The OBE cost projections are created using the Vehicle Sales Forecast (Appendix A) and assumptions about the phase-in by automakers of OBE into the new light-vehicle fleet. The March 2007 report assumed a 2011 introduction of OBE into new vehicles, with one-third of the new fleet equipped, followed by two-thirds in 2012 and full coverage of new

vehicles beginning in 2013. Based on JPO and Task Force guidance, this assumption has been revised to reflect a four-year phase-in starting in 2012. The yearly cost estimates of OBE installations are summarized below. This reflects assumptions about the unit cost, phase-in schedule, and new vehicle sales during these years.

Table 4.6: OBE Installation Costs (In Millions)

	2012	2013	2014	2015	2016	2017	...	2019	...	2029	...	2039	...	2049
FV	$212.7	$428.8	$646.6	$863.4	$864.3	$870.8	-	$893.5	-	$998.8	-	$1,087.4	-	$1,181.2
PV (2008)	$162.2	$305.8	$430.9	$537.7	$503.0	$473.6	-	$424.5	-	$241.2	-	$133.5	-	$73.7

Maintenance
As in the 2007 BCA, it is assumed that each year, 2% of OBE units will require repair or replacement due to electronics failure, software problems, or vehicle damage. The Task Force was unable to provide additional input on this assumption due to antitrust concerns, but overall it was viewed as reasonable given the experience of other onboard electronics. Because it is likely that repair or replacement of OBE will be more expensive than the initial factory installation (due to the absence of economies of scale), the BCA assumes that the repair cost is $100 per unit rather than $50. Based on these figures, the total yearly costs of these repairs/replacements are summarized below.

Table 4.7: OBE Maintenance Costs (In Millions)

	2012	2013	2014	2015	2016	2017	...	2019	...	2029	...	2039	...	2049
FV	$8.5	$25.6	$51.3	$85.4	$119.1	$152.7	-	$219.0	-	$494.4	-	$617.8	-	$690.7
PV (2008)	$6.5	$18.3	$34.2	$53.2	$69.3	$83.0	-	$104.0	-	$119.4	-	$75.8	-	$43.1

Network Backhaul Costs

Estimates for Network Costs were taken from the VII Communications Analysis (table 4-25). This BCA report does not assume a "Phase 1/Phase 2" program as is specified in the communications analysis, and thus the total costs (Phase 2) were used for full deployment and were phased in uniformly over the specific deployment scenario assumed for this report.

In the March 2007 report, a 40 kbps capacity was assumed as the appropriate requirement for operating the day 1 *public* applications. It has become apparent from recent program experience that a 100 kbps requirement is a more appropriate minimum for supporting these applications.

Table 4.8: Network Backhaul One-Time Costs (In Millions)

	2011	2012	2013	2014	2015
FV	$44.3	$44.3	$44.3	$44.3	$44.3
PV (2008)	$36.2	$33.8	$31.6	$29.5	$27.6

Table 4.9: Network Backhaul Recurring Costs (In Millions)

	2011	2012	2013	2014	2015	2016	...	2019	...	2029	...	2039	...	2049
FV	$70.7	$141.5	$212.2	$283.0	$353.7	$353.7	-	$353.7	-	$353.8	-	$353.8	-	$353.8
PV (2008)	$57.8	$107.9	$151.3	$188.6	$220.3	$205.9	-	$168.1	-	$85.4	-	$43.4	-	$22.1

Application Costs

The application costs cover those costs which are specific to a single application and incremental to the other costs of operating and maintaining the VII system.

Development
This report assumes a one-time $10 million cost for developing each VII application. These costs represent the incremental development costs for each additional application. Some examples might be creating new software and algorithms, creating map databases, or designing human-machine interfaces (HMIs) and warning protocols.

Maintenance
There are likely to be some incremental operations and maintenance costs associated with running safety applications using the on-board equipment, such as software and HMI updates, map updates, or additional security layers. 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. For this report, a 5% increase in the likelihood of OBE failure (i.e., from 2% to 2.1%) is assumed for each safety application, which is the equivalent of $0.10 per OBE unit per application per year. A table of the yearly application maintenance cost is below.

Table 4.10: Application Maintenance Costs (In Millions)

	2013	2014	2015	2016	2017	..	2019	..	2029	..	2039	..	2049
FV	$5.1	$10.3	$17.1	$23.8	$30.5	-	$43.8	-	$98.9	-	$123.6	-	$138.1
PV (2008)	$3.7	$6.8	$10.6	$13.9	$16.6	-	$20.8	-	$23.9	-	$15.2	-	$8.6

VII Program and Governance Costs

The VII Program and Governance Costs accounts for the costs incurred at the Service Delivery Node (SDN) and Enterprise Network Operations Center (ENOC) level, including staffing and governance. Current best estimates put the required number of SDNs at 502 (one for each of 452 urbanized areas and for each of the 50 states) and the number of ENOCs at 2 (one central, and one backup).

Development
There are a number of one-time development costs associated with the VII program and governance cost area. First, a $15 million cost is assumed to develop the SDN-ENOC network. Secondly, there is a $200,000 cost assumed for deployment analyses to be done at each SDN, plus a $500,000 for an initial study to standardize the RSE analyses. Total Development Costs equal $115.9 million and would be incurred in 2010.

Installation
All ENOC/SDN installation is also assumed to take place in 2010, concurrent with program development costs, in order to have the ENOCs/SDNs up and running before the

2011 start of RSE deployment. The installation and equipment costs are assumed to be $500,000 per SDN and ENOC. Thus, total Installation Costs are <u>$252 million.</u>

Maintenance, Operations, Staffing etc
The costs associated with maintenance, operation and staffing for the VII program and governance costs are comprised of four costs: (1) capital maintenance costs; (2) operations staffing costs; (3) governance costs (including governance staff costs); and (4) ENOC facility lease. Capital maintenance is assumed to be 20% yearly, yielding a yearly cost of $50.4 million. Operating staff is assumed to be comprised of four crews of four professionals, with a total yearly cost of $9.6 million for the two ENOCs. The governing entity is assumed to cost $6.8 million annually. This cost includes a staff of 26 (3 managers, 20 professional. staff, and 3 administrative staff). The yearly facility lease for each ENOC is $400,000. Total Maintenance, Operation and Staffing Cost would be <u>$62.8 million</u> per year.

Fiscal Impacts

After the 2007 BCA, there were several comments suggesting that it would useful to see VII's costs presented in undiscounted form in order to understand the fiscal impacts. The two charts below attempt to give a picture of the total estimated yearly outlays in each of the 5 cost areas. The first chart shows these values in undiscounted but inflation-adjusted (2008) dollars. The second chart shows these values in undiscounted current year (nominal) dollars, using a GDP Deflator as the estimate of future-year inflation.[13]

Table 4.11: Total Yearly Outlay by Major Cost Area in Future Value, Real (2008) Dollars (In Millions)

	2010	2011	2012	2013	2014	2015	2016	..	2019	..	2029	..	2039	..	2049
RSE	$6.0	$1,042.4	$1,146.7	$1,250.9	$1,355.2	$1,459.4	$521.2	-	$644.7	-	$646.8	-	$641.7	-	$626.1
OBE	$0.0	$0.0	$221.2	$454.5	$697.9	$948.8	$983.4	-	$1,112.4	-	$1,493.2	-	$1,705.2	-	$1,871.9
Net.	$0.0	$115.1	$185.8	$256.5	$327.3	$398.0	$353.7	-	$353.7	-	$353.8	-	$353.8	-	$353.8
Prog & Gov	$367.9	$62.8	$62.8	$62.8	$62.8	$62.8	$62.8	-	$62.8	-	$62.8	-	$62.8	-	$62.8
Apps	$90.0	$20.0	$21.7	$5.1	$10.3	$17.1	$23.8	-	$43.8	-	$98.9	-	$123.6	-	$138.1
Total	$463.9	$1,240.3	$1,638.2	$2,029.9	$2,453.4	$2,886.1	$1,945.0	-	$2,217.5	-	$2,655.4	-	$2,887.0	-	$3,052.7

Table 4.12: Total Yearly Outlay by Major Cost Area in Future Value, Nominal Dollars (In Millions)

	2010	2011	2012	2013	2014	2015	2016	..	2019	..	2030	..	2040	..	2050
RSE	$6.2	$1,078.8	$1,186.7	$1,294.6	$1,402.5	$1,510.4	$539.4	-	$667.2	-	$669.4	-	$664.1	-	$647.9
OBE	$0.0	$0.0	$228.9	$470.3	$722.3	$981.9	$1,017.8	-	$1,151.3	-	$1,545.3	-	$1,764.7	-	$1,937.2
Net.	$0.0	$119.1	$192.3	$265.5	$338.7	$411.9	$366.1	-	$366.1	-	$366.1	-	$366.1	-	$366.1
Apps	$380.7	$65.0	$65.0	$65.0	$65.0	$65.0	$65.0	-	$65.0	-	$65.0	-	$65.0	-	$65.0
Prog & Gov	$93.1	$20.7	$22.5	$5.3	$10.6	$17.7	$24.7	-	$45.3	-	$102.3	-	$127.9	-	$143.0
Total	$480.1	$1,283.6	$1,695.4	$2,100.7	$2,539.1	$2,986.9	$2,012.9	-	$2,295.0	-	$2,748.2	-	$2,987.8	-	$3,159.3

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[13] As reported by the EIA in Annual Energy Outlook 2008. Table 19.0

5. Estimated Benefits of VII-Enabled Applications

Scope

VII's communication capabilities have the potential to enable a variety of applications for safety, mobility, or other purposes, some of which have only just begun to be developed. For the purposes of this BCA, *only one set of potential applications will be analyzed*:

- Signal Violation Warning
- Stop Sign Violation Warning
- Curve Speed Warning
- Electronic Brake Lights
- Advance Warning Information
- Localized Weather/Road Condition Warning
- Winter Maintenance
- In-vehicle Signing
- Ramp Metering
- Signal Timing and Adjustment
- Corridor Management
- Traveler Information
- Electronic Payment
- Private Applications

Overview of Benefit Estimation for Applications

Each of the applications is at a different stage of development with regard to its goals, proposed functionalities, technical requirements, and testing and deployment schedule. Most of the applications are defined as general use cases but do not yet have a detailed "concept of operations" document that would delineate their precise functions and impacts. As such, the calculations in this section are based on information currently available, such as POC testing documents, as well as a set of assumptions that have been developed and documented through the Task Force process. In some cases, as in the March 2007 report, estimation has been deferred because too little information on the application is available. In cases where estimation was possible, the application-specific calculations are presented below. Before examining specific applications, however, a general overview is given of the major categories of benefits and how they are calculated.

For *safety* applications, benefits are calculated based on the reductions in motor vehicle crashes that the application is expected to bring about. This is accomplished through a series of steps:

- First, the application's description is reviewed to determine the types of crash scenarios that it is intended to address. As an example, some applications only apply to rear-end crashes caused by sudden deceleration of the lead vehicle, while others are meant to reduce crashes caused by the violation of a traffic control device.

- Next, crash databases are reviewed to identify the annual number of crashes that fall within the application's scope (as well as the severity distribution of these crashes). This annual crash total is referred to in this BCA as the number of "subject" crashes – i.e. the maximum number of crashes that the application could conceivably address, if it were available to all vehicles at all times and operated flawlessly in all circumstances[14].

- An estimate of the "efficacy" of the application is generated based on a review of the available literature and/or discussions with application developers and safety experts. Efficacy refers to the percentage of subject crashes that the application is expected to prevent, when operating as intended. The actual efficacy of most applications is expected to be substantially less than 100 percent not only due to technical factors such as the possibility of software and hardware malfunctions, but also due to the propensity of drivers to ignore or misunderstand safety warnings or to fail to respond adequately to them.

- Multiplying the number of *subject crashes* by the *efficacy* estimate yields a total number of crashes avoided by the use of the application. For example, an application that is designed to address crash scenarios that account for 100,000 crashes per year, with an efficacy rate of 20 percent, would lead to an estimate of 20,000 avoided crashes per year. (More refined calculations might also be made to estimate the number of crashes that are reduced in severity rather than avoided altogether, as well as the potential for an offsetting increase in other types of crashes.)

- The estimate of crashes avoided is then split out into groups according to assumptions about the severity of these avoided crashes. This calculation yields the number of fatalities prevented and the number of injuries avoided at each level of severity.

- These impact figures – fatalities and injuries avoided or reduced in severity – are then generated for each year of the VII time horizon. This requires adjustments for a number of factors.
    o First, because (in general) only VII-equipped vehicles can reap these safety benefits, the year-by-year estimates must be scaled down in early years according to the expected level of VII in-vehicle penetration at that point. As described in Section 3, this is based on the share of overall VMT by equipped vehicles, since crash exposure is roughly proportional to miles traveled.
    o A second adjustment comes into play for those applications that require the presence of a roadside unit. Since the RSE is being phased in over time, and even at full deployment will not be at every location, expected

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[14] As several Task Force members noted, these figures do not reflect the significant number of crashes, particularly at the lower severity levels, that go unreported and thus do not appear in crash databases. As a conservative and simplifying assumption, no adjustment has been made for unreported crashes.

impacts must be scaled down to reflect the relative presence of RSE at each point. The mechanics of this adjustment vary by application.

- o Third, estimates of avoided crashes must be adjusted to reflect the underlying changes in the prevalence of crashes in future years. While overall exposure to crashes (as measured by VMT) is expected to rise annually, crash rates and fatality rates per vehicle-mile of travel have generally been declining over the decades due to improved vehicle safety and other factors. Because the effect of declining crash rates tends to predominate, future years will have a smaller number of total crashes that could be prevented. This means that estimates of the application's safety impacts must be adjusted downward slightly. A more in depth discussion of the mechanics of this adjustment is presented in Appendix B.

- Finally, the adjusted impact estimates are translated into monetary terms using standardized statistical values for injuries and fatalities. The yearly estimates are then brought into present-value using the appropriate discount rate to yield an overall benefit total for the application.

Note that in cases where existing or ongoing research on potential VII applications has produced estimates of the applications' safety impacts, some of these steps may be skipped or consolidated. Likewise, in cases where detailed information on the severity level of crashes avoided is not available, composite estimates are used that represent a weighted average of crash costs across severity levels for that crash scenario.

Applications that are focused on *mobility* vary a bit more in the calculation of benefits, but in general the approach is to combine statistical information about travel delays with reasonable assumptions about the impacts of the application on traffic flows. Estimates of the total number of hours of delay that would be eliminated by the application are then translated into monetary terms using economic variables, principally the value of time value of money. As with safety applications, these figures must then be carried across each year of the VII time horizon, with adjustments for the level of OBE and RSE in place in each year, and then discounted into present-value terms. Because VMT and hours of travel delay continue to grow each year, calculations of mobility benefits are also adjusted to reflect the greater potential travel time savings in future years. The BCA assumes long-term VMT growth averaging around 1.65% per year, in line with EIA estimates.

A similar approach can be taken for estimating and monetizing the fuel savings, emissions reductions and other *environmental* benefits to be obtained through VII applications. Calculating changes in emissions requires information about the effects of the application on average vehicle speeds and duty cycles, which can then be translated into changes (positive or negative) in the emission of several categories of pollutants, such as carbon monoxide and particulates, which in turn can be monetized using the standardized values discussed in the Core Variables report. The mathematical relationships between vehicle speeds and emissions levels are not only different for each type of pollutant, but also involve complex and non-linear interactions between variables

as diverse as outdoor temperature, relative humidity, and fuel mix. At this stage, the fine-grained information about VII applications' effects on vehicle speeds and duty cycles is not available. This version of the BCA uses a simpler model of emissions avoided, in which the extent of motor fuel saved due to improvements in traffic flow is used to calculate the tons of carbon emissions avoided. (Unlike other pollutants, the carbon content of gasoline is invariable.)

VII Applications – Cost and Benefit Calculations

Signal Violation Warning

As its name implies, this application envisions the use of VII communications to warn drivers that they are at imminent risk of violating a red signal. Specifically, vehicles within the broadcasting range of an intersection-based RSE would receive a broadcast message containing the traffic signal phase status, approach heading, time stamp, stop line location, and weather data. Based on calculations of speed and distance, the driver would receive an in-vehicle warning in cases of potential violation, allowing him or her to take appropriate action to avoid a signal violation and the possibility of a collision.

This is a safety application whose expected benefits include reductions in crash-related injuries and fatalities, reduced crash-related property damage, and reduced crash-related traffic congestion. Benefit estimation was conducted along the lines described above with the following parameters:

- Subject crashes for this application are those involving a vehicle running the red light at a signalized intersection. On the presumption that a warning system is most useful in cases where the signal violation is caused by inattention (rather than willful violation or other factors), the pool of subject crashes is further reduced to those cases in which the driver was inattentive or sleepy. According to analysis of crash databases, these crashes total roughly 113,960 per year[15]. This total excludes cases of driving under the influence of alcohol on the grounds that these types of crashes are not likely to be addressed by the application. In calculations for future years, adjustment is made to account for the effects of rising VMT and historically declining crash rates per VMT.

- The efficacy of the application – i.e. its ability to actually prevent a subject crash at an equipped intersection – is unknown at this point. An initial estimate of 28 percent was used in the March 2007 report based on prior research related to similar types of intersection countermeasures. Several reviewers suggested

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[15] W.G. Najm et al., Volpe National Transportation Systems Center, *Pre-Crash Scenario Typology for Crash Avoidance Research*, Report DOT-HS-810-767, April 2007. In the GES database on which the figures are based, the driver inattention variable is often listed as unknown due to reporting limitations. In this and other similar calculations, the unknown cases are reallocated in the same proportions as the known cases. Though admittedly imprecise, this adjustment appears to be closer to the true value for inattention as found in the Virginia Tech 100-car naturalistic driving study, in which nearly 80 percent of all crashes involved driver inattention.

alternative values, but there was no consensus among the Task Force other than that no "hard data" on this topic would be available until after the CICAS field operational test. In this report, an estimate of 25 percent is used. This reflects the lower bound of the rate of "driver behavior change" as measured in the limited testing that has been conducted as part of Nissan Motor's SKY program in Japan.[16].

- The presence of OBE is required to use the application, so benefits are phased-in according to the fleet penetration estimates, i.e., the share of vehicles equipped, adjusted for the higher VMT of newer vehicles.

- The presence of a roadside unit is also necessary, so benefits are adjusted based on the share of intersection crashes that are expected to occur at RSE-equipped intersections. The deployment scenario calls for roughly 70 percent of urban intersections to be fitted with RSE. Although it is reasonable to presume that RSE installation would be prioritized at those intersections that account for a greater share of crashes, no concrete estimate emerged from the Task Force on this point. As a conservative estimate, it is assumed that 70 percent of intersection crashes occur at the equipped intersections. In the early years of deployment, this figure is adjusted to reflect the 5-year period required for RSE build-out.

- Fine-grained data on the severity levels of the specific types crashes that would be avoided by the use of the application are not yet available. In the March 2007 report, a figure of $54,970 was used to monetize the value of the crashes avoided. This is effectively a weighted average for all crossing-path collisions involving light vehicles – the most common scenario for signal violation, though these crashes can also occur with turning movements. It is a comprehensive figure that includes not only direct economic costs but also injury values and travel delays associated with the crash, and is pegged to the earlier $3.2 million value for transportation fatalities.[17] As noted in Section II, the fatality value has recently been updated to $5.8 million. Since injury values are still reckoned as fixed proportions of the fatality value, and these proportions have not changed, the updated value for crossing path collisions is $99,633. This value is used in the analysis, along with a range for sensitivity testing.

On the cost side, this application requires the use of the VII network, the costs of which have been detailed in Section 3, plus research and development for the application itself and any incremental costs of running the application. In keeping with standard practice

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[16] Masao Fukushima, "Launch ITS from Kanagawa, Yokohama: Progress of SKY Project," Intelligent Transportation Systems World Congress, Beijing, October 2007. SKY includes applications that are analogous to signal violation warning and stop sign violation warning, plus several others (e.g. school zone speed). Although there are some differences in the technology and telecommunications, the applications are conceptually similar to VII. Notably, they entail a *driver warning* rather than automated vehicle control.
[17] L. Barr, M. daSilva, and J. Hitz, "Safety Benefits/Cost Assessment of Potential IVI Safety Systems," Volpe National Transportation Systems Center, Project Memorandum, September 2000.

in benefit-cost analysis, upfront application development costs are excluded from the calculations to the extent that they are "sunk" costs made prior to a deployment decision, that is, if they would be incurred regardless of whether the investment in VII ultimately is made.

Based on the assumptions detailed above, over the course of the project lifetime this application is estimated to yield safety benefits of $11.0 billion in present-value terms, plus $0.1 billion in mobility benefits due to reduced crash-related congestion.

Stop Sign Violation Warning

The Stop Sign Violation Warning application is analogous to Signal Violation Warning, but warns drivers of potential violations of stop signs rather than traffic signals. Again, based on calculations of speed and distance, the driver would receive an in-vehicle warning in cases of potential violation, allowing him or her to take appropriate action to avoid violating the stop sign. One important difference is that this application is envisioned as being powered by a database of stop sign locations, rather than by direct communication of intersection-based RSE. (This is related to the fact that stop signs always require a stop, unlike traffic signals where it is necessary to broadcast the current signal phase.)

This is a safety application whose expected benefits include reductions in crash-related injuries and fatalities, reduced crash-related property damage, and reduced crash-related traffic congestion. Benefit estimation was conducted with the following parameters:

- Subject crashes for this application are those involving a vehicle running a stop sign at a stop-controlled intersection. As with the signal violation application, this is further reduced to those crashes involving driver inattention, and excluding alcohol involvement. Analysis of crash databases indicates that these crashes number about 19,304 per year[18].

- As with the signal violation warning application, the efficacy of the application is assumed to be 25 percent, based on initial results from Nissan's SKY project.

- The presence of OBE is required to use the application, so benefits are phased-in according to the fleet penetration estimates, again adjusted for VMT growth in future years.

- The presence of a roadside unit at each intersection is assumed to be unnecessary, since the technical approach described above uses a map database instead that requires only a general RSE coverage in the area. Therefore, the impacts and benefits have not been adjusted based on RSE intersection presence, though this assumption will be revisited based on application design and testing results. To

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[18] W.G. Najm et al., Volpe National Transportation Systems Center, Pre-Crash Scenario Typology for Crash Avoidance Research, Report DOT-HS-810-767, April 2007.

be conservative, estimates in the initial years have been adjusted to reflect the required five-year build-out of the RSE network.

- As with the signal violation application, a composite value of $99,633 is used to monetize the value of the crashes avoided.[19]

Total safety benefits for this application are estimated at $2.7 billion in present-value terms. There is also a small mobility benefit associated with reductions in crash-related congestion.

Curve Speed Warning

The curve speed warning application would provide an in-vehicle warning to the driver if the vehicle's speed is higher than the recommended speed for the curve. The system can be designed to receive the information from RSE or to use the on-board equipment and a downloaded navigation map to make an assessment. In the first case, the RSE compares the vehicle speed with the recommended speed and sends a signal to the vehicle if there is a potential danger. In the latter case, the OBE compares the vehicle speed to the recommended speed that is stored with the navigation map data. Road condition data can also be used in this process to fine-tune the speed warning based on weather and other factors.

This is a safety application whose benefits include reductions in crash-related injuries and fatalities, reduced crash-related property damage, and reduced crash-related traffic congestion. The main focus of the application is on roadway departure crashes involving light vehicles negotiating a curve, where excessive speed for conditions is the primary contributing factor. Benefit estimation was conducted with the following parameters:

- Subject crashes are those where the pre-crash scenario is a control loss without prior vehicle action, and the pre-event movement is negotiating a curve. To be conservative, crashes involving alcohol are again excluded due to uncertainty about the applicability of the application in these cases. These subject crashes total approximately 162,932 per year[20]. A further adjustment for the effects of widespread adoption of electronic stability control on light vehicles is discussed below.

- The efficacy of this application is estimated at 25 percent. Although the SKY project does not include a curve warning, this is roughly the level of "driver

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[19] Barr, daSilva, and Hitz, op. cit., updated to reflect new USDOT guidance.

[20] W.G. Najm et al., Volpe National Transportation Systems Center, Pre-Crash Scenario Typology for Crash Avoidance Research, Report DOT-HS-810-767, April 2007. Although this application is intended to provide warning of excessive speeds, subject crashes are not necessarily limited to those in which the driver was listed as speeding. In many road departure crashes, the loss of control is due to the vehicle going too fast for the prevailing road conditions, even though the driver may not have been exceeding the posted limit and/or may not have been cited for speeding.

behavioral change" observed for the other warnings. This efficacy estimate will be updated as more information becomes available.

- The presence of OBE is required to use the application, so benefits are phased-in according to the fleet penetration estimates, adjusted for VMT.

- The updated comprehensive value of avoiding a road departure crash – the most common type associated with curve speed warning – is $110,327, which is the weighted average across severity levels.[21]

- The calculations assume the use of the map-based approach mentioned above, which requires general RSE coverage rather than the presence of a roadside unit at each curve location. Thus estimates of impacts have not been adjusted based on RSE presence, except to reflect the required five-year system build-out. These assumptions will be revisited based on application design and testing results.

The Task Force discussed whether this application offers benefits beyond what can be achieved using vehicle-autonomous systems, as well as the extent to which rising use of electronic stability control (ESC) can serve to prevent many of the same types of road departure crashes. There is uncertainty on both issues, though it is clear that the VII approach offers the additional benefit of being able to incorporate road weather and traction information into the warning algorithm to produce more effective warnings. It has been suggested that this application is complementary to ESC inasmuch as ESC can help drivers who are warned of excessive speed to maintain control of their vehicles as they reduce speed while approaching or negotiating a curve. Further study of the Curve Speed Warning application will be needed to resolve these issues. At this point, to be conservative and avoid possible double-counting of crashes avoided, before calculating benefits, the estimate of the baseline number of road departure crashes (subject crashes) was reduced by 67,466, which is the lower-bound estimate of annual crashes avoided due to the upcoming mandatory installation of ESC on vehicles[22]. (As with the other safety applications, the benefits calculated also reflect an assumption that overall crash rates in future years will be lower than in the present, due to other innovations and safety practices.)

Based on these assumptions and values, the total safety benefits for this application are approximately $14.6 billion in present-value terms. There is an additional $0.1 billion in mobility benefits from reduced crash-related congestion.

Electronic Brake Lights

The electronic brake lights application would provide a warning to the driver in case of the sudden deceleration of a forward vehicle. The OBE of the lead vehicle would send a

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[21] Barr, daSilva, and Hitz, op. cit., updated to reflect new USDOT guidance.

[22] National Highway Traffic Safety Administration, *Final Regulatory Impact Analysis: FMVSS No. 126, Electronic Stability Control Systems*, March 2007, Table IV-10.

signal to other vehicles if its longitudinal deceleration exceeds a predetermined threshold, thereby allowing following drivers to be aware of this deceleration even if their visibility is limited by weather conditions or obstructed by large vehicles. The in-vehicle application would provide a warning to the driver in a manner to be determined by the automobile manufacturers. When coupled with a GPS, this application can also give information about the exact location of the decelerating vehicle. The warning message would be irrelevant and unused if the relative positions of the decelerating and "listening" vehicles are such that no crash threat exists, e.g., if the vehicles are in different lanes.

This is a safety application whose benefits include reductions in crash-related injuries and fatalities, reduced crash-related property damage, and reduced crash-related traffic congestion. Benefit estimation was conducted with the following parameters:

- Subject crashes are assumed to be those involving a following vehicle approaching a decelerating lead vehicle, with inattention (including sleepiness) on the part of the driver of the following vehicle. Crashes involving alcohol are excluded. The annual total of these subject crashes is 221,673[23].

- The efficacy of this application is estimated at 25 percent. Although the SKY project does not include a curve warning, this is roughly the level of "driver behavioral change" observed for the other warnings. This efficacy estimate will be updated as more information becomes available.

- For this application to function as intended, *both* the lead (decelerating) vehicle and the following vehicle must be equipped with OBE – the lead vehicle needs the equipment to be able to send the safety message and the following vehicle needs it in order to receive and process the message. Therefore, the benefits of this application are phased-in according to the fleet penetration estimates, adjusted for VMT, based on the likelihood that both vehicles would be equipped.

- The updated comprehensive value of avoiding a rear-end crash is assumed to be $57,284, which is a weighted average across severity levels and again includes economic costs, injury values, and crash-related congestion costs.[24]

- Calculations assume that this is essentially a vehicle-to-vehicle application, in which case the presence of a roadside unit at each specific location is assumed to be unnecessary. The impacts and benefits have not been adjusted based on RSE presence or for the five-year RSE build-out period. Again, this assumption will be re-visited as necessary.

Safety benefits for this application are estimated at $13.6 billion in present-value terms, with an additional mobility benefit of $0.2 billion from reductions in crash-related congestion.

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[23] W.G. Najm et al., Volpe National Transportation Systems Center, Pre-Crash Scenario Typology for Crash Avoidance Research, Report DOT-HS-810-767, April 2007.
[24] Barr, daSilva, and Hitz, op. cit., updated to reflect new USDOT guidance.

Ramp Metering

Ramp meters are used to regulate the entrance of vehicles onto congested expressways, which helps to prevent breakdowns in the smooth flow of traffic and to maintain higher average travel speeds. They are currently used in several U.S. metropolitan areas. This VII application envisions the use of OBE-RSE communication to provide traffic management centers with detailed, real-time data on traffic flow, speeds, and other vehicle conditions (such as traction control and antilock braking activation, which are proxies for road surface conditions) from probe vehicles. This information would be used to optimize the operation of the ramp meters.

This optimization could take several forms, ultimately including the development of algorithms that would allow each ramp meter to change its signal timing dynamically in response to changing conditions on the ramp and on the freeway mainline. VII-supplied data on traffic conditions on the freeway and nearby surface streets could also be used to ensure that the ramp metering does not merely shift congestion to the arterial network.

In POC testing documents and other descriptions, however, the application has been construed more narrowly: VII-supplied probe vehicle data would be used for periodic offline analysis of ramp traffic flows so that adjustments could be made in the signal timing plans. The application is also currently described as something that would be applied to existing ramp meters; the installation of additional meters is not part of its scope.

Several members of the Task Force noted that constraining the definition of the application to this relatively limited functionality tends to result in under-estimation of the mobility benefits. VII data could allow for fully dynamic metering algorithms, and by lowering the cost of metering, could encourage the adoption of ramp metering in many other locations around the country. However, other Task Force members favored a conservative approach that does not assume the existence of future capabilities beyond what is currently being tested. This BCA uses the latter approach and calculates the benefits of VII-enabled ramp meters as an improvement over existing benefits from metering.

As with other mobility-oriented applications, the benefits of ramp metering are, in large part, a function of the number of hours of travel time that motorists would save (i.e., delays avoided) through its use. According to the Texas Transportation Institute's 2007 Urban Mobility Study, the use of ramp meters produces an annual reduction in travel delays equal to 38.6 million person-hours. This figure is for the 25 medium- to large-sized metropolitan areas that employ ramp metering, though most of the total comes from a handful of large conurbations that make extensive use of it. TTI's calculations are based on simulation modeling, which in turns draws on results from a real-life experiment from the Minneapolis-St. Paul area in late 2000, when the region's ramp meters were turned off temporarily and a before-and-after study was conducted.

This BCA looks not at the total benefits of ramp metering, but rather at the *additional* benefits that could be obtained by using VII data to periodically improve the signal timing plans. The magnitude of this effect depends in large part on how aggressive local transportation agencies are in using VII data to fine-tune their metering algorithms. A review of the literature on ramp signal timing suggests that improved algorithms could be expected to produce a roughly 5 to 10 percent improvement in travel times, taking into consideration not only the freeway mainline but also the ramp traffic and nearby arterial roads.[25]

Based on these research findings, a 5 percent improvement over existing conditions is assumed. Deployment of this VII application would thus be expected to produce an additional reduction in delay equal to just under 2 million person-hours per year at full deployment.

In producing calculations for individual years, it is assumed that this optimization can take place only once a certain critical-mass of vehicles (5 percent of the fleet) are OBE-equipped to serve as probes. The 5 percent figure was suggested by the Task Force. Once sufficient probe data are available, non-equipped vehicles can benefit from improved ramp timing just as much as equipped vehicles. Adjustment has been made to account for future growth in VMT at the levels described in the fleet model (Section 3), since additional vehicle traffic translates into additional potential for delay reductions[26]. Adjustment has also been made to account for the required five-year deployment phase-in of RSE; in other words, benefits are lower in the initial years because not all of the RSE would yet be in place.

Hours of delay savings have been valued at $11.20 per hour, which is the more conservative of the values of time (VOT) shown in Section 2 and is therefore used in the absence of more fine-grained information on the impacts on local versus long-distance vehicle travel. This calculation yields travel time savings benefits of $22 million in the first year of full operation, growing thereafter due to VMT growth.

The hours of delay avoided also represent a savings in motor fuel. Results from the TTI Urban Mobility Study indicate that 0.65 gallons of gasoline are consumed per hour of travel delay (a weighted average across large metro areas). Therefore, the travel time savings calculated for the VII Ramp Metering application are estimated to result in a fuel savings of just over 1.2 million gallons per year at full deployment, with a value of $2.8 million. The fuel savings also represent just over 11,000 tons of CO_2 emissions avoided per year, with a value of at least $6,000.

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[25] M.A. Hadi, "Coordinated traffic responsive ramp metering strategies -- an assessment based on previous studies," presented at 12th World Congress on Intelligent Transport Systems, San Francisco, November 2005.

[26] The adjustment assumes a linear relationship between VMT and congestion. Task Force members noted that congestion can grow more quickly than VMT, particularly at the metro area level. This assumption is therefore somewhat conservative.

Combining travel time, fuel savings, and emissions avoided, the total mobility benefits over the BCA analysis period, in present value terms, are $0.3 billion.

The net incremental costs of this application are arguably very close to zero, because all that is required is data analysis and periodic re-timing of ramp signals – something that state and local DOTs already do for their ramp meters, though with different data sources. There would undoubtedly be some start-up costs associated with developing the algorithms to translate raw RSE data into a usable format and the software to use this information at traffic management centers, along with the costs of periodic software updates. These costs would potentially be offset by the substantial cost savings stemming from the fact that VII probe data would largely eliminate the need for certain traffic monitoring equipment, such as loop detectors at on-ramps.

Signal Timing and Adjustment

As with the ramp metering application, this is a probe vehicle application that envisions the analysis of OBE- and RSE-collected data to improve signal timing and reduce delay. In this case, data on traffic flows and vehicle movements at intersections would be used to make periodic improvements to traffic signal timing plans – changing the allocation of green time to reduce overall delays. Another similarity to the ramp metering application is that it is envisioned as an incremental improvement to existing delay-reduction strategies and does not involve significant new hardware (except for the core VII systems themselves).

Many state and local DOTs have installed advanced signal equipment and implemented timing plans, so again the benefits of the application rest on the question of how much *incremental* benefit could be obtained by taking advantage of the VII-generated data for these timing plan updates. Task Force members noted that one of the major advantages of VII-collected probe data is that it would allow the collection and analysis of data on actual (rather than imputed) vehicle speeds and stop-start patterns at intersections. This would allow for more efficient signal timing and/or creation of "green wave" patterns.

The Texas Transportation Institute's 2007 Urban Mobility Study estimates that signal timing adjustment produces an annual reduction in travel delays equal to 16.7 million hours across the nation's 85 largest metropolitan areas. A review of the literature on traffic signal timing suggests that improved algorithms could be expected to produce an improvement in travel times in the range of 8 to 15 percent, mostly by reducing stopping delays.[27] Taking a midrange value of 10 percent improvement as a result of VII's superior data – a rough estimate also suggested by Task Force members – the incremental benefit of the application is therefore approximately 1.7 million hours of delay reduction,

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[27] Institute of Transportation Engineers, "Toolbox for alleviating traffic congestion and enhancing mobility," USDOT Report FHWA-SA-98436, 1997; UK Department for Transport, "Understanding the Benefits and Costs of ITS – A Toolkit Approach," Adaptive Signal Control summary table, www.itstoolkit.co.uk.

1.1 million gallons of gasoline saved, and 9,600 tons of CO_2 emissions avoided per year once full deployment is reached.

Calculations of future-year benefits assume, based on guidance from the JPO, that the software and algorithms for this application will be available for use in 2013. At that point, OBE penetration would be approximately 6.5 percent, which is believed to be sufficient to produce usable probe-vehicle data. As with the benefit calculations for Ramp Metering, adjustment has been made for the five-year deployment period of RSE and the future growth in VMT.

In addition to the initial start-up costs of this application in terms of data-processing algorithms, there are the costs of analyzing the data, generating new signal timing plans, and then changing the timing at individual intersections – which may require, in some cases, sending a staff person out to the controller box to make a manual adjustment. Because this application is described as using existing equipment and processes, however, these costs would be incurred irrespective of VII. Indeed, Task Force members stated that VII represents an opportunity to lower the costs of timing optimization efforts, because expensive, on-site traffic counting can be replaced with analysis of VII probe data. Some loop detectors used to count traffic could also be eliminated, though loops that are used to detect the presence of a vehicle at an actuated signal would need to be maintained for many years because of the continuing presence of non-VII vehicles in the fleet.

Applying the standard monetary values of travel time savings, gasoline saved, and CO_2 emissions avoided, discounting future benefits into present values, and summing across the relevant portion of the project time horizon yields total benefits for the application of $0.3 billion.

Winter Maintenance

The basic concept of this application is that via RSU-OBE communication, weather-related information from probe vehicles – e.g. wiper activation, outside temperature, use of headlights, use of traction control – would supplement road weather information system (RWIS) data in order to give highway maintenance crews a better picture of current conditions. Maintenance crews would use this information to respond more quickly and effectively to areas requiring salting or other treatments, optimizing their use of materials and personnel resources. Travelers would see somewhat better and safer road conditions.

RWIS and probe vehicle data appear to be complementary. RWIS provides some of the more fine-grained meteorological data (e.g. snowfall rates, wind speed and direction) that cannot be easily captured by probe vehicles. However, RWIS sensors are expensive, tend to be spread thinly, and are not always able to yield data on the direct effects of weather on vehicle and highway operations. The key piece of information for snow and ice treatment is road surface temperature. The Winter Maintenance use case description

mentions that VII data would be "incorporated into the MDSS [Maintenance Decision Support System] Road Condition and Treatment Module" along with RWIS sensor data and other weather information to estimate road surface temperature and then to calculate the recommended maintenance treatment. According to the use case, information from probe vehicles could include the vehicle speed; location; altitude; the state of the wipers, heating, and defroster systems; the thermometer/infrared temperature sensor; and the state of the traction control and antilock braking systems. Although none of these give the road surface temperature directly, algorithms can be developed to translate this information into road surface estimates. The benefits of the Winter Maintenance application (as distinct from RWIS) are a function of the extent to which VII probe vehicle data could improve the quality and scope of weather data and the associated decision-support tools, versus what could be achieved with RWIS alone.

One way of modeling these benefits is to estimate the cost savings accruing to state and local agencies from more efficient winter operations. Previous research has described[28] the benefits of using point-specific forecasts of road surface temperature to guide winter maintenance decisions. The underlying concept is that the natural properties of water and salt are such that increasingly more salt is needed to melt ice at lower temperatures. For example, at 30 degrees, a pound of salt can melt 46.3 pounds of ice, but at 10 degrees, the same pound of salt can only melt 4.9 pounds of ice. (Other de-icing chemicals exhibit similar properties.) Because the exact road surface temperature is usually unknown, and because the consequences of under-treating are generally greater than those of over-treating, highway departments tend to use more salt (and the associated labor and machinery) than is strictly necessary. RWIS and other systems that provide detailed, point-specific forecasts and readings of road surface temperature (not air temperature) can help identify areas where less salt can be safely used. This translates into savings on materials and labor, without any reduction in roadway level of service. There are also environmental benefits from the reduction in salt and chemical run-off.

As an example, at 30 degrees, the Vermont Agency of Transportation calculated that the level of salt required is 80 pounds per lane-mile (pplm). A "typical" application by the Iowa DOT is 220 pplm, which represents an additional cost of about $2.28 per lane-mile. For a statewide storm in Iowa, being able to use the lower salt-application rate would result in about $59,000 in savings for one pass of the state highway network. The savings are greatest at temperatures near the freezing point.

A starting point for these calculations is the fact that highway agencies in the U.S. spend approximately $2 billion per year on winter maintenance.[29] One estimate in the literature is that an RWIS-powered Maintenance Decision Support System could produce savings in the range of 10 to 15 percent of winter maintenance costs.[30] Based on this

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[28] Smith, D.E., and J.A. Zogg, "Economic evaluation of advanced winter highway maintenance strategies," Proceedings of "Crossroads 2000" Conference, Iowa State University, 1998.

[29] FHWA, Office of Operations, "Winter Maintenance Virtual Clearinghouse: Technical Briefs," http://ops.fhwa.dot.gov/weather/resources/publications/tech_briefs/tech_briefs.htm.

[30] FHWA, Turner-Fairbank Highway Research Center, "A new support system for winter maintenance," *Focus*, September 2004.

figure, a very rough estimate of the *incremental* cost savings from supplementing RWIS data with VII-supplied data might be in the range of 2 percent of winter maintenance expenses (net of the costs associated with any necessary processing software). By simple arithmetic, a 2 percent savings on the country's annual $2 billion expenditure on winter maintenance works out to a savings of $40 million per year. Beginning with an assumed start date of 2012 and summed up across the VII project time horizon, this equals roughly $0.4 billion (in present-value terms) in cost savings.

In addition, VII-generated probe vehicle data could provide enormous value to the nation's meteorological enterprise, even beyond the transportation community. Just as weather observations from ships and aircraft are used as additional sources of weather data, observations from the many VII-equipped vehicles traveling on the roadways could also provide forecasters with information about weather conditions. Feasibility studies on this topic suggest that, although technical challenges exist in harvesting and fusing the vehicle-based data, an opportunity exists to significantly improve the quality of weather data available for the atmospheric boundary layer (i.e., the portion closest to the ground) for applications such as identifying precipitation types[31]. The direct society-wide benefits of improved forecasting would be substantial, for example in higher crop yields, reduced property damage due to severe weather, reductions in aviation delays, improved emergency preparedness and disaster response. Given that the nation's weather-related damages total in the billions annually, any improvement in forecasting ability and lead times would represent significant benefits. At present, however, it is not possible to quantify those benefits with any degree of specificity.

Advance Warning Information
Localized Weather/Road Condition Warning
In-Vehicle Signing
Traveler Information

The applications in this cluster are all designed to enhance the level of information provided to motorists, allowing them to avoid unsafe situations and road congestion, and generally make better-informed travel choices. At this stage of the applications' development, it is clear that the focus of each is slightly different. However, there are enough areas of overlap among them that the most logical evaluation approach may be to consider their costs and benefits as an overall "package."

The advance warning information application would use RSE to broadcast information to vehicles in the vicinity, with information on accidents, work zones, detours, traffic congestion, travel time, weather, parking restrictions, turning restrictions, and the like.

The localized weather/road condition warning application is similar, except that it makes use of information gathered from vehicles themselves and their sensors. This information

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[31] K. Petty and W. Mahoney, "Weather Applications and Products Enabled Through Vehicle Infrastructure Integration (VII): Feasibility and Concept Development Strategy," prepared for ITS JPO by National Center for Atmospheric Research, Research Applications Laboratory, Boulder, Colo., January 2007.

would then be processed at an operations center and sent back to vehicles approaching the affected area via RSE. As an example, vehicle sensor data and inputs such as activation of stability control, rate of change of steering wheel, traction control state and windshield wiper status of the vehicle would provide an assessment about the road surface conditions.

The in-vehicle signage application would provide fixed and variable highway sign information to the driver – essentially a complement to the roadside signage already in place. Specifically, the RSE would send relevant signage information to the vehicle's OBE as the car is approaching the area.

The traveler information application would involve expanding and extending current traveler information efforts – highway message signs, telephone hotlines, traffic websites, and so on – with the benefit of RSE- and OBE-collected information on traffic flow, speeds, road weather, pavement conditions, and incidents. The goal is to allow travelers to make better informed decisions about where and when to travel and which routes to take, thereby improving safety and reducing travel delays.

Taken as a group, these applications have a mix of safety and mobility benefits. On the safety side, they assist motorists by providing them with information about road conditions, which might range from a warning about a particular patch of black ice 200 yards ahead to a regional warning about a forecast of flash floods later in the day. Knowing what to expect helps drivers maintain control over their vehicles in difficult conditions and allows them to make well-informed choices about where and when to travel, or even whether to travel at all. For these reasons, the safety benefits of these applications would primarily come from a reduction in crashes caused by unexpected changes in conditions, poor weather, and other similar factors.

Mobility benefits – principally time savings – would come from these applications, particularly the traveler information application. Many states have already invested in traveler information systems such as traffic websites and 511 telephone information systems; research and surveys show that travelers believe that these services can help them save time by avoiding incidents and congested roadways. Traveler information can also help drivers plan efficient routes, avoiding navigational errors and wasted mileage.

While the safety and mobility benefits of these applications are obvious enough in general terms, their concepts of operations have not yet been defined in sufficient detail to allow meaningful quantification of the benefits. For example, producing an estimate of the number of crashes that would be avoided due to roadway condition warnings requires additional information about the types of warnings that would be provided, their geographic scope or range, the crash scenarios that they would be intended to address, and the likely reactions of drivers. Although there is now a substantial literature on traveler information services, a review of this literature did not provide adequate information to estimate these factors.

Indeed, on the mobility side, much of this literature points out the extreme difficulty of estimating the time-savings benefits of traveler information, as this is very context-specific. Travelers who adjust their routes or departure times according to reports of delays and congestion sometimes save time, but often do not because of outdated information or rapidly changing conditions. VII, with its more comprehensive and timely data, would change this situation. Papers cited in the ITS Benefits Database[32] suggest, based on modeling and simulation work, that information on current conditions on freeways and arterials generates reduction in peak travel times of 1.5 percent to 3.4 percent. Taking the low value of this range for the purposes of an illustrative calculation, a reduction of 1.5 percent in the nation's *incident-related* congestion delays (i.e., delays caused by crashes, construction, and other anomalies, as distinct from "recurring" delay that is due solely to traffic volume) is equivalent to a savings of over 30 million person-hours per year, with a value of $350 million. Adjusting for the required RSE phase-in period and the effects future increases in VMT, these time savings sum to approximately $4.6 billion in present-value over the 40-year time period[33].

In a future revision to this BCA, a more sophisticated calculation along these lines may form the basis of a consolidated benefits estimate for this group of four applications. At present, however, the Task Force was in agreement that it is not yet possible to generate meaningful quantitative estimates of the safety and mobility impacts, and the above is presented only to provide a sense of the magnitude of potential benefits.

One area of benefit that does permit more defined quantification is the cost savings that could be realized by state and local transportation agencies. Task Force members from state DOTs noted that, over time, VII's probe data would begin to eliminate the need for costly traffic surveillance equipment, such as loop detectors, toll-tag readers, and cameras. (Cameras would still be valuable in certain locations, and loop detectors would still be needed for some situations, such as actuated traffic signals, until VII's fleet penetration was at or near 100 percent. However, loops used for traffic counting could begin to be phased out as soon as reliable probe data became available.)

Likewise, VII's in-vehicle delivery of traffic information would eventually obviate the need for highway-mounted variable message signs. Task Force members from state DOTs stated that when VII fleet penetration reached 50 percent, they would most likely no longer purchase new VMSs or replace aging ones. Task Force members also provided the following parameters for estimating the associated savings: upfront costs of $272,500 per VMS unit, annual maintenance costs of $11,600 per unit, and a useable lifespan of 10 years. Based on this information, an inventory of current VMSs from the ITS Deployment Database, and the fleet penetration estimates described earlier, a model of VMS maintenance costs and expected replacements was constructed. Comparing the

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[32] M. Jensen et al., "Metropolitan Model Deployment Initiative Seattle Evaluation Report: Final Draft," Report for Federal Highway Administration, Report No. FHWA-OP-00-020, 2000, *and* K. Wunderlich and J. Larkin, "Impacts of Supplementing Web-Based Urban Freeway ATIS with Parallel Arterial Travel-Time Data," presented at 7th World Congress on ITS, Turin, 2000.
[33] Based on TTI Urban Mobility Study 2007 and assuming that incident-based delay comprises 50% of total delay (the figure is higher in most metropolitan areas).

stream of VMS-related costs in the with-VII and without-VII scenarios, the difference is approximately $0.9 billion in present-value terms over the relevant portion of the project lifespan. This represents a cost savings for state and local agencies and is included as a benefit in this BCA model.

Corridor Management

The Corridor Management concept calls for uniform data (on traffic volumes, speeds, etc.) from probe vehicles to be provided to state and local transportation authorities, allowing them to more effectively manage traffic at the "corridor" level. Corridor is used here to mean sections of freeways and nearby parallel arterials, often spanning multiple states or jurisdictions, and possibly including parallel transit facilities. Corridor information could also be provided to the public to allow better-informed travel decisions.

The Corridor Management application has been split into two use cases, with updated descriptions from the VII Working Group. The "load management" use case involves using real-time VII data to allow transportation agencies to balance travel demand across adjacent or parallel facilities more efficiently. In practice this would be accomplished through the combined use of traffic signals, ramp metering, and lane control systems, along with traveler information conveyed via radio, dynamic message signs, 511, and commercial outlets. The idea is that travel delays can be reduced by re-directing traffic (either directly via signals or lane controls, or indirectly via information and guidance) onto roads/facilities to make "best use of available resources." Some examples might include changing the direction of a reversible lane in response to an incident, changing the ramp-metering timing plan to maintain freer-flowing highway traffic, or using roadside message boards to encourage motorists to divert to a different route.

The second use case is called "planning assistance" and refers to the ability of VII to "revolutionize" the data-gathering component of local and regional transportation planning. Instead of intermittent traffic/cordon counts for selected locations, planners would receive extensive data on vehicle volumes and speeds throughout the network and across all times of day, dates, and seasons. Likewise, origin-destination travel demand is currently estimated using personal surveys, census data, and computer models of travel decisions. VII would replace much of the "guesswork" that is inherently part of this process with more accurate counts of origin-destination travel. (The use case description notes that the tracking of vehicles from origin to destination would need to be an "opt-in" application due to privacy issues.) The benefits would accrue to communities in the form of more effective transportation and land-use planning, inasmuch as new roads, transit services, ITS, and other transportation investments could be developed with a much richer set of data on current conditions.

The "planning assistance" component of corridor management has the potential to bring enormous long-term benefits to metropolitan areas. Its trove of real-world data could help guide the development of transportation facilities and land-use plans that more

closely meet the needs of communities. This is particularly true for fast-growing parts of the country where new roads and transit systems are being built to accommodate population and job growth. The difficulty in estimating benefits comes from the fact that these benefits accrue over a very long time horizon and that it is difficult to identify a "base case." Moreover, the availability of even the most detailed data does not change the fact that transportation investments are ultimately political decisions that may not be fully data-driven. One more easily quantifiable benefit is the reduction in traffic data-collection costs that localities will realize once VII is active. Personal surveys and travel diaries (used for origin-destination counts) can be particularly expensive and subject to respondent error or design biases.

Regarding the "load balancing" component, most of the information in the ITS Benefits database and other literature relates to the impacts of particular interventions, such as adaptive signal timing, rather than the cumulative impacts of an overall corridor-level management approach. However, a few papers deal with the impacts of balancing traffic loads between freeways and adjacent arterials in a corridor approach. One report[34] summarizes the effects of using signal timing changes, ramp metering, and message boards. Impacts were tested both by simulations and by field tests in the Glasgow, Scotland area in March 1998. The field tests showed improvements in afternoon-peak hour journey times of 13 percent across the urban network when all elements (ramp metering, intersection control, and message boards) were deployed. Another report, which was based solely on simulations,[35] tested the effects of balancing traffic loads across facilities after an incident on Interstate 29 in the Fargo, North Dakota area. Simulation results indicated travel time reductions of between by 8 and 18 percent depending on the approach.

This information provides some indications of the relative magnitude of potential benefits. However, estimation of the costs and benefits of the two corridor management use cases has again been deferred until additional information about the specific approaches is obtained.

Electronic Payment

The basic premise of this application is that vehicle OBE, combined with "opt-in" personal information including billing details, would be used in conjunction with RSE to enable wireless payments. Some likely candidates for electronic payment would be roadway tolls and parking fees, since in many areas electronic payments using toll tags (such as E-ZPass) is already widespread. VII, with its additional telecommunications capabilities and wider coverage, would also open up the possibilities for partnerships with private industry that could enable motorists to make convenient wireless payment for other goods and services, such as gasoline or take-away meals.

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[34] Diakiki, Christina, et al. Application and Evaluation of the Integrated Traffic-Responsive Urban Corridor Control Strategy (IN-TUC) in Glasgow.

[35] Birst, S., and A. Smadi, "An evaluation of ITS for incident management in second-tier cities: a Fargo, ND case study," accessed via ITS Benefits Database.

Electronic toll collection is the subject of many articles in the ITS literature; its benefits include significant reductions in delays and vehicle emissions at toll plazas, along with lower collection costs for toll authorities. In some sense, VII-enabled toll collection would simply replace the current 900 MHz toll-tag transmissions with VII's 5.9 GHz communications. However, because VII envisions OBE installed on every vehicle, this could eventually lead to much more widespread usage of electronic toll collection and thus greater time-savings and emissions benefits. Transportation agencies could also realize substantial cost savings by phasing out manual toll collection, and motorists using VII-equipped vehicles might realize savings by not having to purchase a separate toll tag.

Toll payment will still need to be an opt-in application because of the inherent privacy and billing issues. Although the opt-in rate could conceivably be no higher than the current participation rate in toll tag programs, it is hypothesized that the greater convenience of being able to pay with standard vehicle equipment (versus a separate transponder that must be acquired from the toll authority) would tend to increase motorists' participation in electronic toll collection. At this stage, however, the extent of any such increase is not known.

For non-toll, private sector payments, there is a clear case for potential benefits, since VII would be enabling entirely new capabilities. It will not be possible to quantify these benefits until more is known about the uses that automakers and others intend to make of the VII system. The Task Force process was unable to shed light on this area because of antitrust considerations, which prevented the automaker representatives from discussing future products and plans.

Private OEM Applications

It is envisioned that VII will allow the automakers to develop and implement a number of applications that will provide value to their customers. Some of the examples that have been discussed center on place-based commerce and customer relationship management, e.g. the ability to deliver customized service messages to the vehicle. As mentioned above in the discussion of electronic payments, these capabilities have not been shared with the BCA team due to antitrust considerations, and quantification of their benefits is not currently possible.

6. Summary Results and Next Steps

This report has presented a framework for assessing and calculating the benefits and costs of VII, including the establishment of the core economic variables to be used in converting impacts into monetary terms. Section 4 presents an estimate of the overall life-cycle costs of VII, based on current assumptions about deployment schedules and equipment. In Section 5, each of the proposed applications has been reviewed and, wherever possible, a preliminary estimate of the application's benefits and incremental costs has been produced.

As discussed in Section 1, the net benefits of VII have been construed as consisting of the combined benefits of the various VII-enabled applications, net of the life-cycle costs of VII's infrastructure and operations and any incremental costs of the applications themselves. The calculations are summed across VII's 40-year horizon and calculated in present-value terms using a base year of 2008. In keeping with conventional BCA practice, all dollar values are in real terms, in this case 2008 prices.

As Table 6.1 shows, these calculations indicate that the VII initiative, with the set of applications considered here, would generate net benefits of approximately $16.9 billion. The benefit-cost ratio is 1.6 to 1.

These calculations of benefits are "conservative" in the sense that they do not yet include:
- Envisioned future enhancement of several applications, e.g. the use of fully adaptive traffic signal control
- Additional applications that may be developed, including private-sector applications
- Any estimate of safety benefits related to un-reported crashes
- The full value of emissions reduction benefits stemming from reductions in crash-related congestion
- The mobility benefits associated with improved traveler information systems
- Benefits to enterprises outside of transportation, particularly meteorological forecasting
- The potential to achieve a fuller measure of benefits more quickly through the use of aftermarket OBE and/or retrofitting of older vehicles
- Extension of the VII concept to public transportation and commercial vehicles.

Table 6.1. Summary of Estimated VII Benefits and Costs
(Present Values, Billions of 2008 Dollars)

Application / Cost Element	Safety Benefits	Mobility Benefits	Costs
Signal Violation Warning	11.0	0.1	
Stop Sign Violation Warning	2.7	0.0	
Curve Speed Warning	14.6	0.1	
Electronic Brake Lights	13.6	0.2	
Ramp Metering		0.3	
Traffic Signal Timing		0.3	
Winter Maintenance		0.4	
Traveler Information		0.9	
Total Benefits	**41.8**	**2.4**	
Roadside Equipment			9.3
Onboard Equipment			12.4
Network Backhaul, O&M			3.7
Governance & Program			1.0
Application-Specific Costs			0.8
Total Costs			**27.3**
NET BENEFITS: 16.9 **B/C RATIO: 1.6**			

In considering the expected benefits and costs of VII, it is also important to understand the extent to which these estimates will vary based on different assumptions, inputs, and key parameter values. Table 6.2 provides a summary of some of the "sensitivity cases" that have been tested to date and their influence on the estimated benefits and costs of VII. The results of this testing demonstrate the sensitivity of the results to assumptions about the costs of the onboard equipment and the effectiveness of safety applications, suggesting that these may be fruitful areas for further research and analysis as the benefit-cost estimates continue to be revised.

Table 6.2. Summary of Initial BCA Sensitivity Testing

	Present Values in Billions of 2008 Dollars			B/C Ratio
	Benefits	**Costs**	**Net Benefits**	
VII BCA Base Case (All Values as in Report Text)	44.2	27.3	16.9	**1.6**
Sensitivity Case Tested:				
Discount Rate of 3%	104.2	57.4	46.8	**1.8**
30-Year Project Horizon	37.6	24.7	12.9	**1.5**
OBE Costs Double ($100/installation, $200/replacement)	44.2	39.7	4.5	**1.1**
Backhaul Requires 500 kbps Bandwidth	44.2	29.2	15.0	**1.5**
Future VMT is 20% Higher than Estimated	50.3	27.6	22.7	**1.8**
Future VMT is 20% Lower than Estimated	37.9	26.9	11.0	**1.4**
Safety Applications: 15% Effectiveness Rate	27.3	27.3	0.0	**1.0**
Safety Applications: 35% Effectiveness Rate	61.1	27.3	33.8	**2.2**

Appendix A: Baseline Vehicle Miles Traveled and Fleet Model

Baseline Vehicle Miles Traveled (VMT)

Calculating the benefits and costs of VII requires the creation of a model of the turnover of the light vehicle fleet as well as a baseline forecast of vehicle miles traveled (VMT). This will allow modeling of how VII on-board equipment (OBE) will filter through the vehicle fleet and subsequently how quickly benefits from this technology will begin to accrue to road users.

For the purposes of this VII cost/benefit analysis, we need to be able to isolate the VMT of VII-equipped vehicles. This requires initially developing a model of the nation's fleet of light vehicles and then forecast how it grows and how its composition changes over time. Using new light vehicle sales forecast data and scrappage rates we can determine how vehicles, and in particular those equipped with OBE, will travel through the vehicle fleet over time. Once the fleet model is constructed, total VMT for each year is derived by aggregating VMT for each fleet age cohort within a year. Within this forty year forecast, we also are able establish and isolate the VMT total for VII equipped vehicles as they are introduced into the nation's fleet.

Building a Vehicle Fleet Model

The first step in creating a VMT forecast is done through establishing the age structure of the current stock of light vehicles. This was done separately for passenger cars and light trucks. Using data sourced from R.L. Polk & Co. as a starting point, a cross-sectional view of the 2006 light vehicle fleet was built. These age structure data are presented in Figure 1. Age zero represents new vehicles in a given year and provides a cross-sectional view that covers 28 years for light trucks and 30 years for passenger cars.

Figure A.1:

Age Structure of Light Vehicle Fleet (2006)
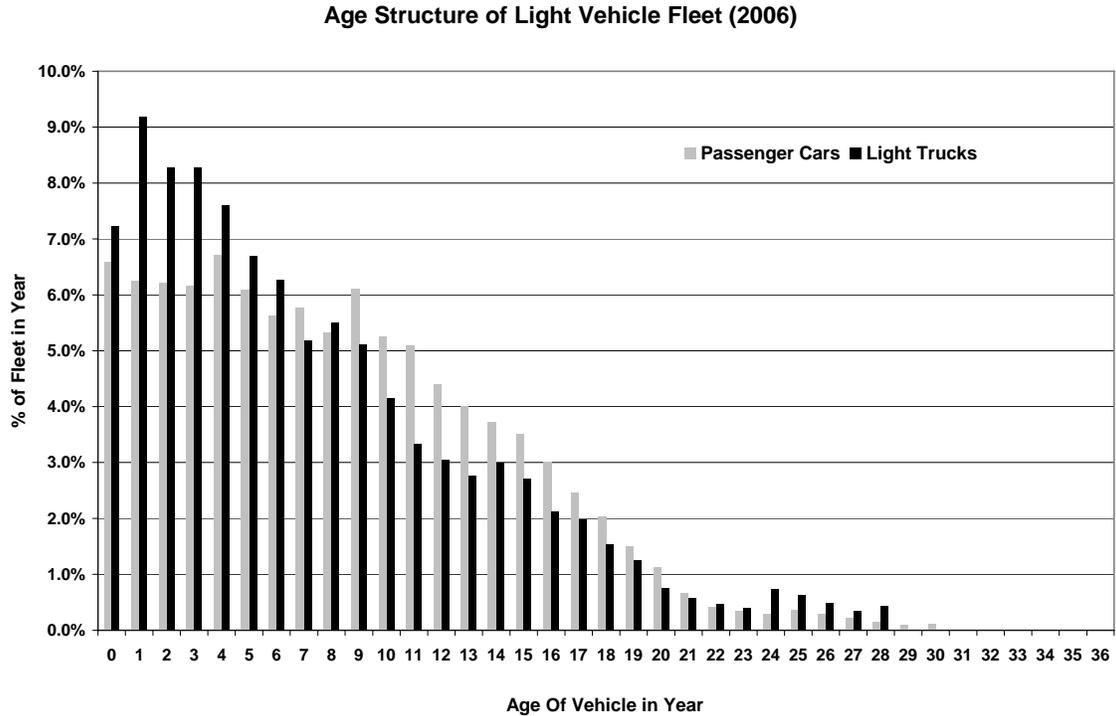
These age distributions were then applied to the total 2006 stock for passenger cars and light trucks, as determined by R.L. Polk & Co., providing our baseline fleet age structure.

To be able to forecast the fleet structure, by age, through our forty year horizon, we need to introduce new vehicles into model as they are sold and brought into the fleet, while at the same time removing vehicles as they are scrapped (i.e., permanently removed from service in the vehicle fleet).. In the case of new light vehicles entering the fleet, data were obtained from the Energy Information Administration's 2007 Annual Energy Outlook. This report provided forecasts for passenger car and light truck sales through 2030. To obtain a forty year horizon required for the VII benefit/cost analysis, we extended the EIA auto sales forecast using the average annual growth rate between 2004 and 2030 as the growth rate between 2031 and 2055. This was done for total auto sales (passenger cars plus light trucks), which had a historical growth rate of 0.8%, and for passenger cars, which had a historical growth rate of 0.5%. The forecast for light trucks was then calculated as the residual between total sales and passenger car sales (Figure 2).

Figure A.2:

Light Vehicle New Sales Forecast
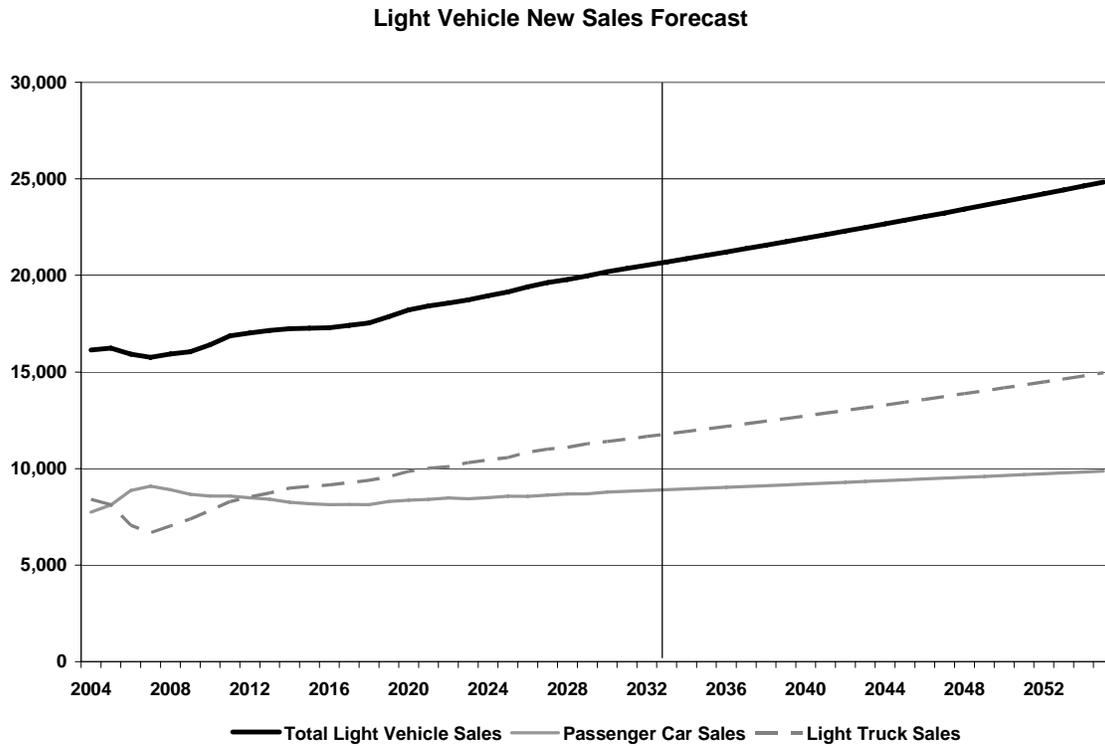
In the long run, the forecast of light vehicle sales shows a gradual increase in the level of new vehicle sales per capita (which have been expressed in thousands for simplicity), rising from around 55 light vehicles sold per thousand population in 2004 to slightly more than 57 in 2055 (Figure 3). In figure 3, the line labeled Linear (Auto Sales Per Capita (thousands)) shows a linear trend of this series.

Figure A.3:

Light Vehicle Sales per Capita (1,000's)
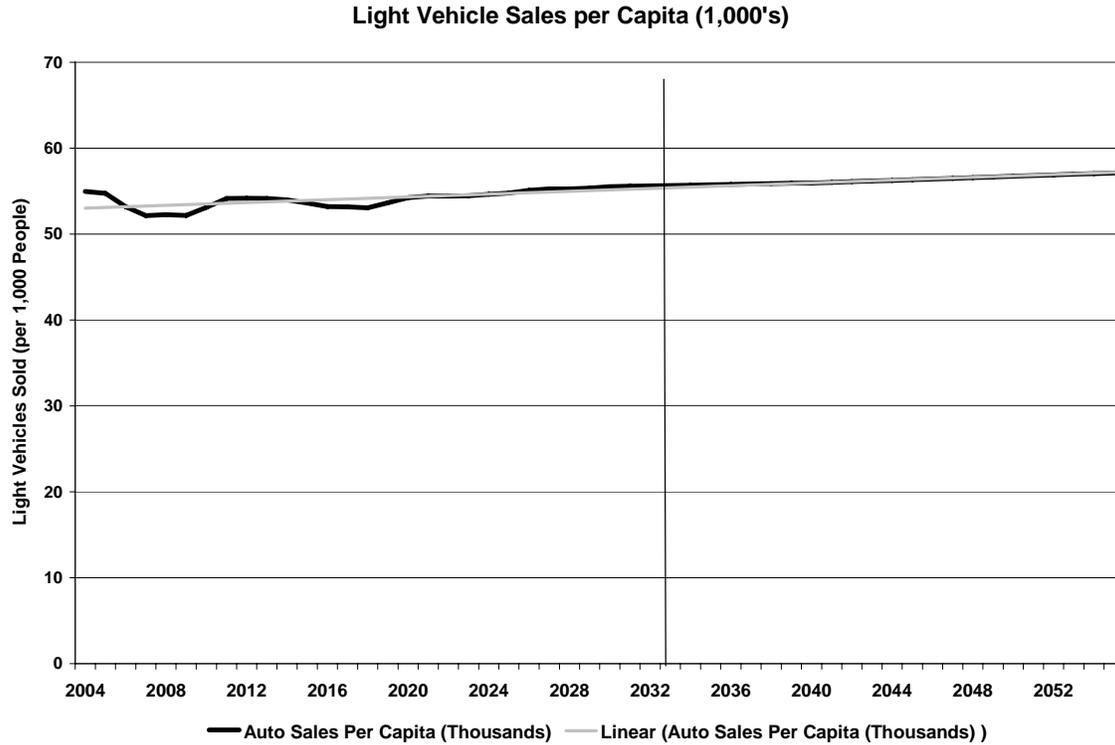
For 2006, we incorporated the new vehicles for both passenger cars and light trucks into the baseline fleet structure. The construction of the 2006 fleet within the VII model, created through using age characteristics and new sales, can be represented mathematically as:

$$\text{Fleet}_{2006} = \sum_{(i=1 \text{ to } t)} (\text{Fleet Stock}_{2006}) * \% \text{ Fleet}_{(t)} + \text{new sales}$$

Where:
- Fleet_{2006} = Current estimate of fleet stock in 2006, aggregating the stock by age cohort and including new sales.
- $\text{Fleet Stock}_{2006}$ = Polk's estimate of the 2006 vehicle stock
- t = age cohort of vehicles within the fleet stock for 2006
- %Fleet = percent of fleet stock that is age t
- New Sales = new light truck or passenger car sales

Our calculations for both the passenger car and light trucks fleets in 2006 were more than 98% of Polk's estimate of overall fleet size.

These baseline fleet distribution characteristics for 2006 were used to forecast the structure of the fleet through 2055. For each new forecast year, every fleet cohort from the prior year was aged one year (i.e. cars that where one year old in 2006 moved to the 2 year old cohort in 2007). At this point, as vehicles move from one age cohort to the next,

it is necessary to account for scrappage. This is done through utilizing the conditional probability that a vehicle will "survive" – i.e. remain in service in the vehicle fleet – from one year to the next. These scrappage rates, derived from R.L. Polk & Co data, are presented in Figure 4.

Figure A.4:

Light Vehicle Conditional Scrappage Rates
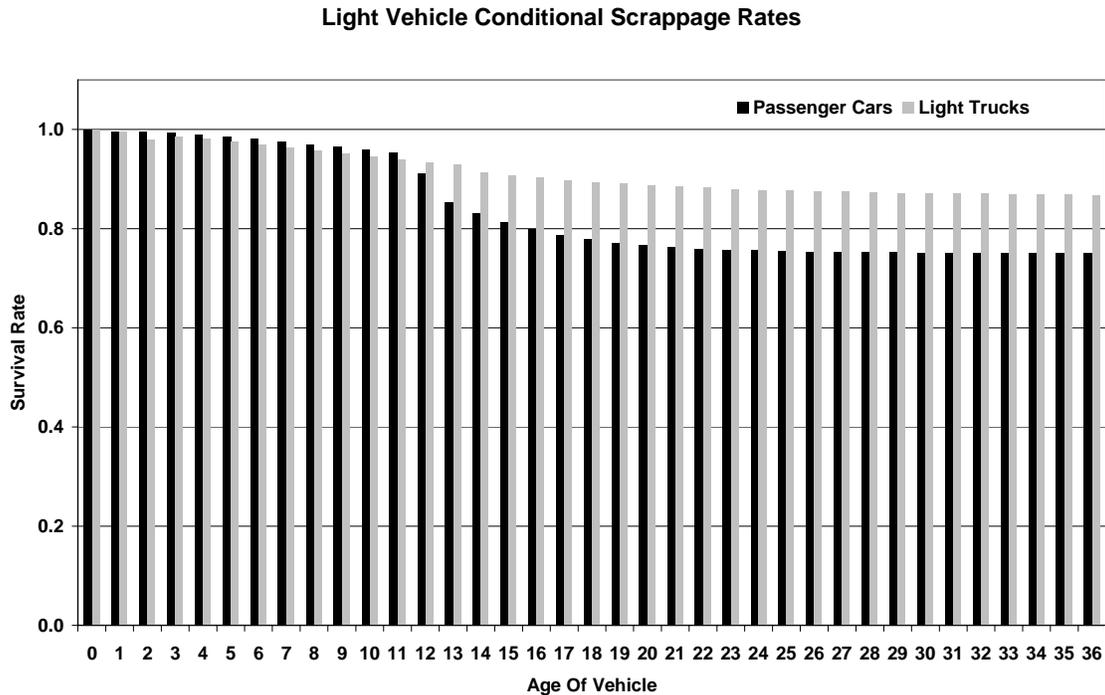
Essentially, these rates tell us the percentage of vehicles that will survive from one year to the next. In the early years, almost all light vehicles will survive to the next year, but as time moves on this survival rate will diminish. The conditional scrappage rate differs between passenger cars and light trucks. While in the early years of use the scrappage rate between these two types of vehicles is similar, beyond the 10 year mark the trends diverge. In large part this is due to the longer useful lifespan of vehicles within the light truck category, due to a number of reasons such as their propensity to be retained by households for occasional use. Within our VMT model we have made the minor simplifying assumption that all vehicles older than 36 years are scrapped and removed from the fleet.

Using the conditional scrappage rates, along with the fleet stock in 2006 and new vehicle sales we are able to create a forecast of the fleets of passenger cars and light trucks from 2006 through 2055. Mathematically this is represented as:

Fleet (year$_t$, cohort $_{i=1to36}$) = Fleet (year$_{t-1}$, cohort$_{i-1}$) * Scrappage rate (cohort$_{i-1}$)

Within each year, new sales of vehicles are introduced at year = 0.

Introducing VII On-Board Equipment to the Fleet of Vehicles

After creating a fleet forecast, we then need to incorporate the introduction of VII technology within our model. We are assuming that VII on board equipment (OBE) will be introduced during a four year period running from 2012 through 2015. This process is assumed to be incremental, with 25% of new vehicles sold in 2012 being equipped, 50% being equipped in 2013, 75% being equipped in 2014 and 100% equipped in 2015. After 2015 all new light vehicles sold in the US will come equipped with VII OBE. Within our model structure we adjust the number of vehicles in the early years of VII by the percent of new vehicles that are VII equipped. These vehicles will then filter through the fleet model in the same proportion during subsequent years. Starting with new sales in 2015, fleet age cohorts will be comprised entirely of VII equipped vehicles. Over time, more and more of the fleet will be comprised of VII equipped vehicles. By 2021 more than half of the fleet will be VII-equipped, by 2026 three-quarters of the fleet will be VII-equipped, and towards the end of the 2030s essentially the entire fleet will be VII-equipped.

Figure A.5:

VII Light Vehicle Fleet Penetration
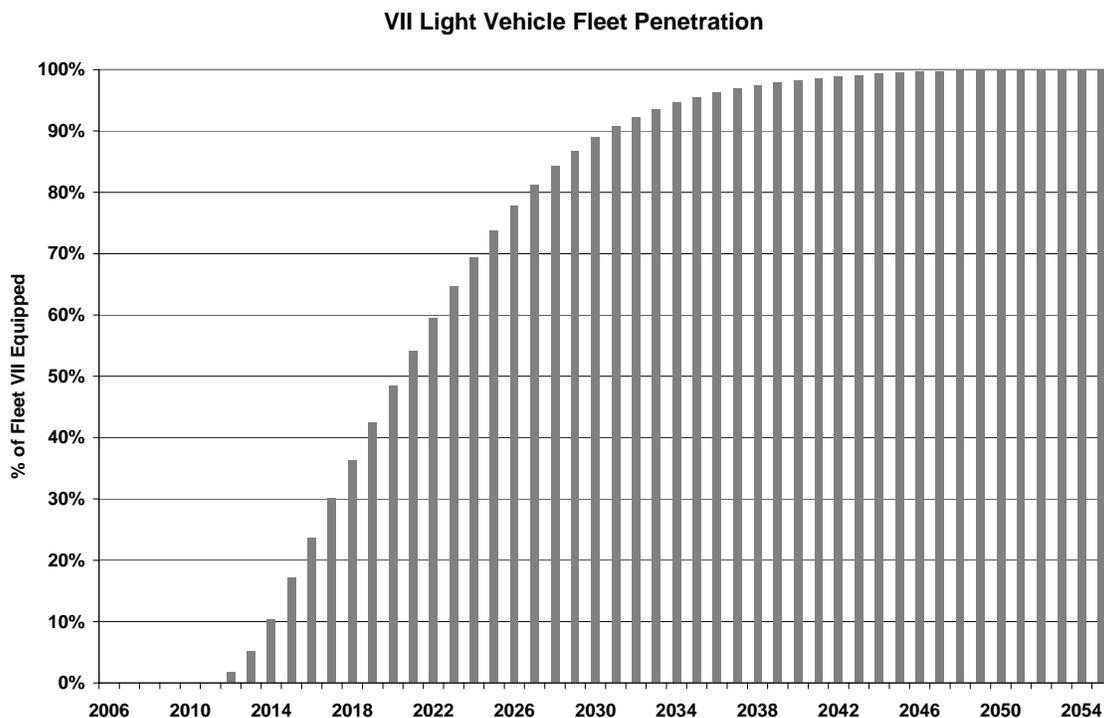
Determining Vehicle Miles Traveled

The fleet forecast is now used to determine the vehicle miles traveled (VMT) for the fleet and vehicles with and without VII OBE. This is done through utilizing an estimate of the average miles driven by age of vehicle in 2006, which were derived from R.L. Polk & Co data. These mileage schedules show that new vehicles are expected to be driven much more than older ones, which is a function of their reliability and other factors, while light trucks have a higher VMT profile than passenger cars, particularly in the outer years.

Figure A.6:
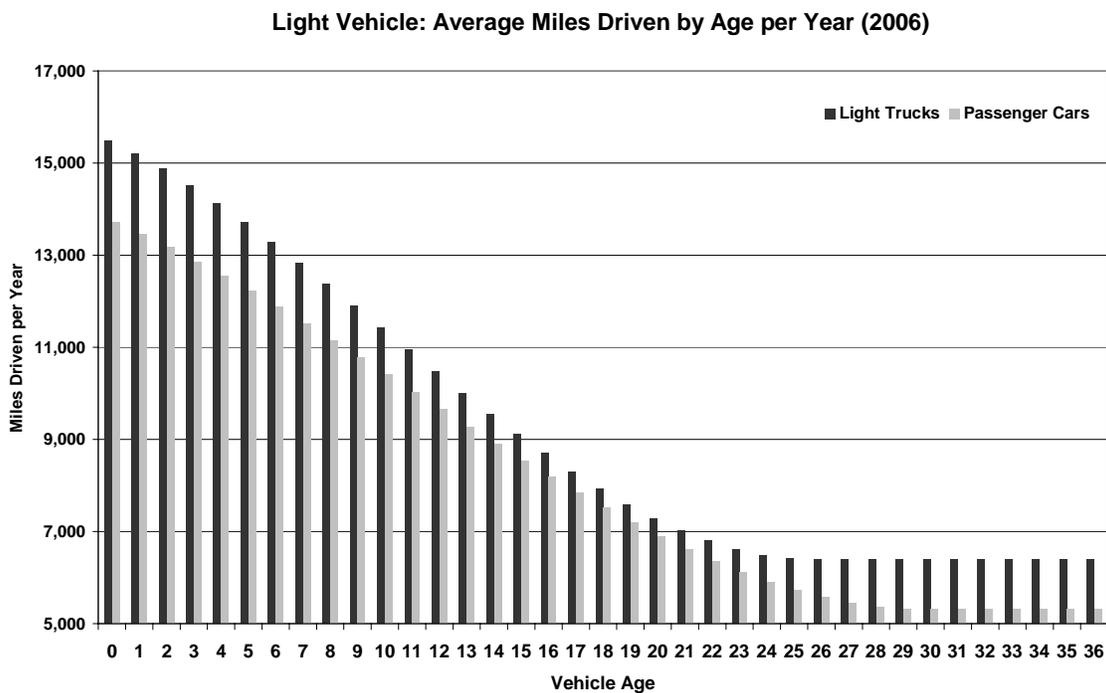
Determining the miles driven by vehicle for a given age is modeled as follows:

VMT (year$_t$, cohort $_{i=1to36}$) = Fleet (year$_t$, cohort$_{i=1to36}$) * Average Miles Driven (cohort$_{i=1to36}$)

As VII equipped vehicles enter the fleet we are able to isolate the VMT driven by these automobiles. To do this the calculation detailed above is modified slightly to account for the introduction years of VII equipped vehicles into the light vehicle stock.

VMT (year$_t$, cohort $_{i=1to36}$) = Fleet (year$_t$, cohort$_{i=1to36}$) * Average Miles Driven (cohort$_{i=1to36}$) * (% vehicles VII equipped)

Between 2012 and 2014 a portion of the light vehicle stock will be VII equipped and as these vehicles age the model will move these cohorts through the fleet structure and calculate the VMT accordingly. Beyond 2015, all new vehicles will be VII equipped and the equation will revert back to the first one above to follow these vehicles through the age cohorts.

Our expectation is that like VMT, average miles driven by age of car would gradually increase over time. (That is, the overall rise in VMT over time would manifest itself not only in a growing vehicle fleet, but also in gradual increases in the annual mileage of each vehicle.) Since our average driving information is only a cross-section for one year (2006), an adjustment to this data was made during the forecast period to ensure we are accounting for the increase in average driving done per car over time. To validate this adjustment, the EIA light vehicle VMT forecast is used as a control and comparison. Combining the VMT forecasts through 2055 for passenger vehicles and light truck vehicles we obtain a total VMT forecast for the light vehicle stock. This was then compared with the light vehicle forecast presented by the EIA in its 2007 Annual Energy Outlook. Since we have used input data from the EIA model in our VII work, it would seem reasonable to calibrate our total VMT forecast with the EIA model. Thus, an adjustment was made to the average miles driven by age by year data to bring our VMT forecast in line with the EIA. From 2011 onward, the average miles driven data per year was increased by a constant 0.8% for both passenger cars and light vehicles. With this adjustment in place, our VMT forecast was 101% of the EIA VMT forecast in 2012 (at the introduction of VII) and was at 96% of the EIA total in 2030, which is the end year of the EIA forecast. Although our forecast is slightly lower than the EIA VMT forecast, it remains within 5% over the forecast period. A final validation of the VII VMT forecast was done through comparing its growth rates with those of other publicly published VMT forecasts. The VII VMT forecast and other publicly published ones are detailed below:

Table A.1: Comparison of VMT Forecasts

VII BCA MODEL
Annual Average Growth 2012-2030 = 1.68%
Annual Average Growth 2031-2055 = 1.66%
Energy Information Administration 2007 Annual Energy Outlook[36]
Annual Average Growth 2006-2030 = 1.88%
National Surface Transportation Policy and Revenue Study Commission[37]
Annual Average Growth 2005-2030 = 1.82%
Annual Average Growth 2035-2055 = 1.72%
Center for Urban Transportation Research[38]
Case 1: Annual Average Growth 2001-2025 = 1.74%
Case 2: Annual Average Growth 2001-2025 = 2%
U.S. Department of Transportation's 2006 Transportation Research, Development and Technology Strategic Plan[39]
Annual Average Growth 2000-2030 = approximately 1.6%
Federal Highway Administration Status of the Nation's Highways, Bridges and Transit[40]
Annual Average Growth 2004 – 2024 = 1.92%

Overall, the total light vehicle VMT forecast created for the VII benefit cost analysis appears to be relatively consistent with the other VMT forecasts presented above. Although the VII VMT growth rate is slightly lower than the other forecasts, these models utilize different methodologies, leading to the differing outlooks. VMT growth is also calculated over different time frames for the various forecasts, which will also have an effect on the reported compound annual growth rates. The VII forecast fits within the range of growth rates, which has a low of 1.6% and a high of 2%. While it sits at the lower end of this range, this does mean we are taking a more conservative approach in terms of capturing the amount of VMT being driven by VII equipped vehicles,

[36] http://www.eia.doe.gov/oiaf/archive/aeo07/index.html

[37] http://www.transportationfortomorrow.org/final_report/chapter_2.aspx

[38] The Case for Moderate Growth in Vehicles Miles of Travel: A Critical Juncture in U.S. Travel Behavior Trends. *Steven E. Polzin, Center for Urban Transportation Research, University of South Florida, April 2006.*

[39] Transportation Research, Development and Technology Strategic Plan (2006-2010). *US Department of Transportation November 2006*

[40] Status of the Nation's Highways Bridges and Transit: Conditions and Performance Report. Chapter 9: Impacts of Investments. *Federal Highway Administration (2002, 2004, 2006)*

particularly during the initial transition years of the program. In addition, due to the linear nature of the VII model, particularly the adjustment being made to average miles driven by each vehicle, the VMT growth rate is relatively steady during the entire forecast period, falling only slightly in the outer years.

The VII VMT model's clear advantage for our purposes is that it allows us to easily decompose and isolate the number and level of travel by VII equipped vehicles as they enter and then pass through the light vehicle fleet. Being able to make this distinction is important as we assume that the benefits from most safety applications would rise in proportion to VMT traveled by VII equipped vehicles. In addition, since new vehicles are driven disproportionately more than older ones, the benefits of VII, which are dependent upon VMT, will accrue faster than just the introduction of VII equipped vehicles would suggest. Indeed, when calculating the cost of VII OBE we are focused on the actual cost of installing this system into vehicles, which is determined by the number of new light vehicles sold each year.

Figure A.7:

OBE Equipped Vehicles
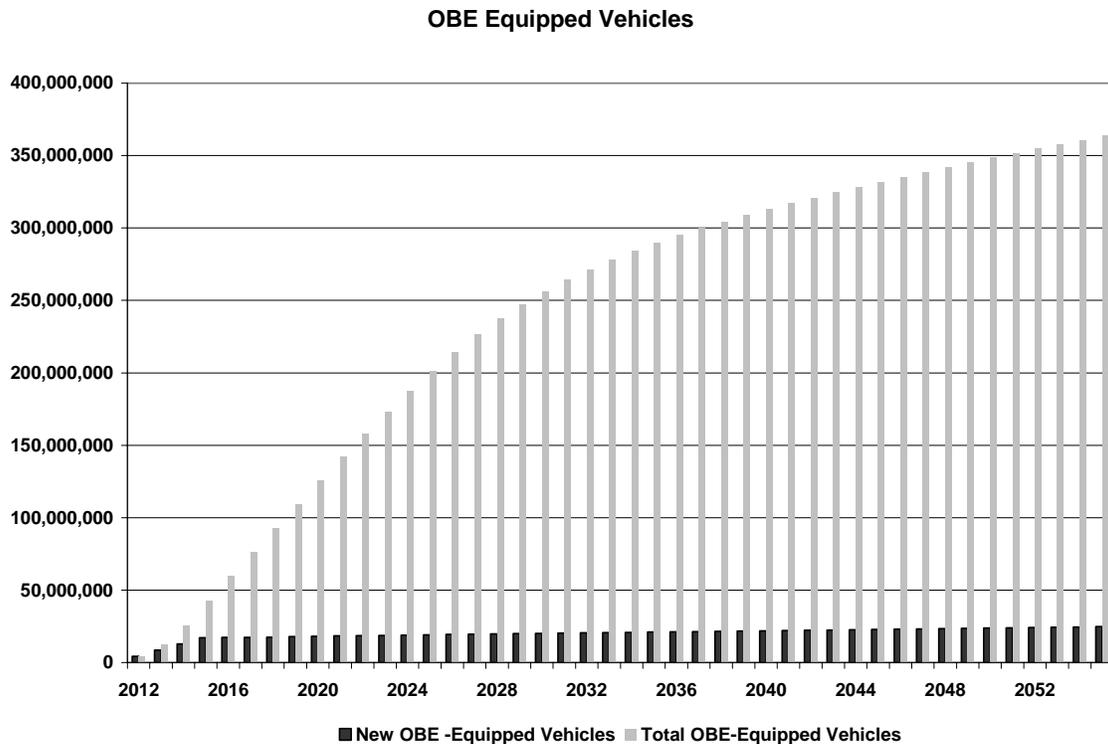
Appendix B: Baseline Crash Forecast

A key component of the VII benefit-cost analysis methodology is the calculation of a baseline crash forecast. This needs to be done to enable us to measure the benefits, in terms of crashes avoided, from the introduction of VII technology into the light vehicle fleet. For the purposes of this study we are focused on baseline crash forecasts related to the four safety applications analyzed:

1) Signal Violation Warning: Crashes related to vehicles violating a red signal
2) Stop Sign Violation Warning: Crashes relate to vehicles violating a stop sign
3) Curve Speed Warning: Loss-of-control crashes related to excessive speed while negotiating a curve
4) Electronic Brake Lights: Rear end collisions involving a decelerating lead vehicle

Data for total crashes, including the scenarios outlined above, were obtained through the GES database which is maintained by the National Highway Traffic Safety Administration (NHTSA). As with the VMT forecast model, the crash data used to create the VII crash baseline was for passenger cars and light trucks only.

For the purposes of the VII work, we focused initially on creating a forecast of total crashes for light vehicles through 2055. Our forecasting methodology assumed that VMT would play a significant role in the crash totals; the more miles driven, the higher the exposure to potential crash situations. Since VMT data are not available at a low-enough level to associate directly with the scenarios being analyzed for this study, the top-line crash forecast is then used as a guide for projecting crashes at a more detailed level. Along with the amount driven (VMT), other factors such as the age and experience of drivers and the introduction of new safety technology, such as electronic stability control, will likely also play a role in affecting the level of crashes.

Since a high in 1996, when light vehicle crashes peaked at close to 6.8 million, there has been a general downward trend in the number of crashes to slightly less than 6 million in 2006 (Figure 1). Nonetheless, if data back to 1990 are viewed, this trend becomes less apparent. Overall, the history of light vehicle crashes in this period does not have an obvious trend that would suggest a pattern that would provide a strong basis for a forty year projection.

Figure B.1:

Total Light Vehicle Crashes
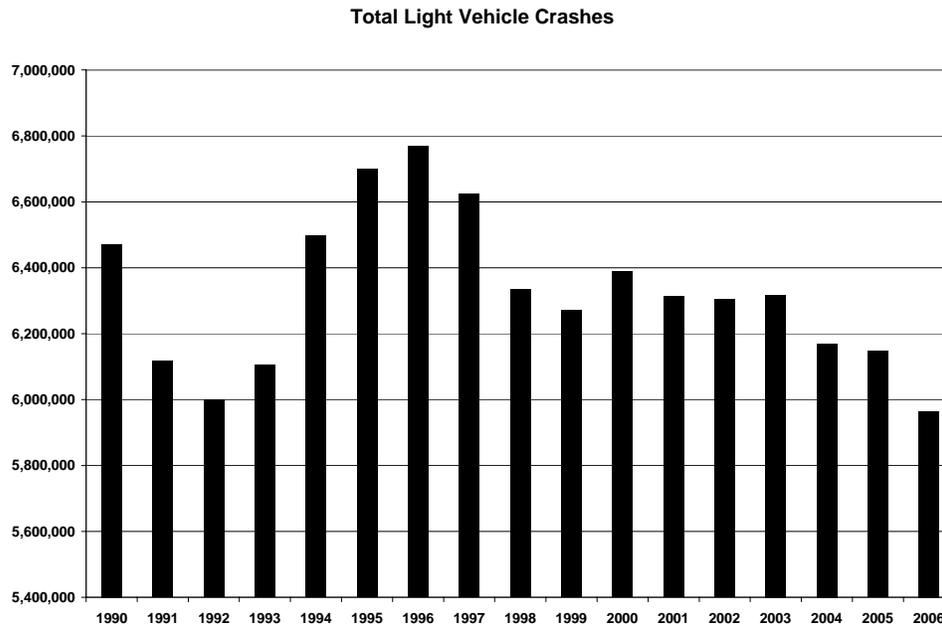
Viewing the crash data normalized per VMT provides a more revealing view of the historical trends within the crash data. This plot (Figure 2 below) shows a relatively steady downward trend in crashes per VMT from 1990 through 2006. By 2006, crashes per million VMT were down to 2.2, compared with more than 3.2 in 1990. Even as VMT, or the potential exposure to crashes, has increased, there has been a decline in the relative number of crashes. This implies that there has been a relatively steady improvement in the safety of road travel during this 16 year period. This improvement in safety is likely due to the introduction of new automotive technology that makes driving safer, along with outreach and enforcement efforts, graduated licensing schemes, and potentially the effects of demographic changes amongst the driving-age population.

Figure B.2:

Total Light Vehicle Crashes Per Million VMT
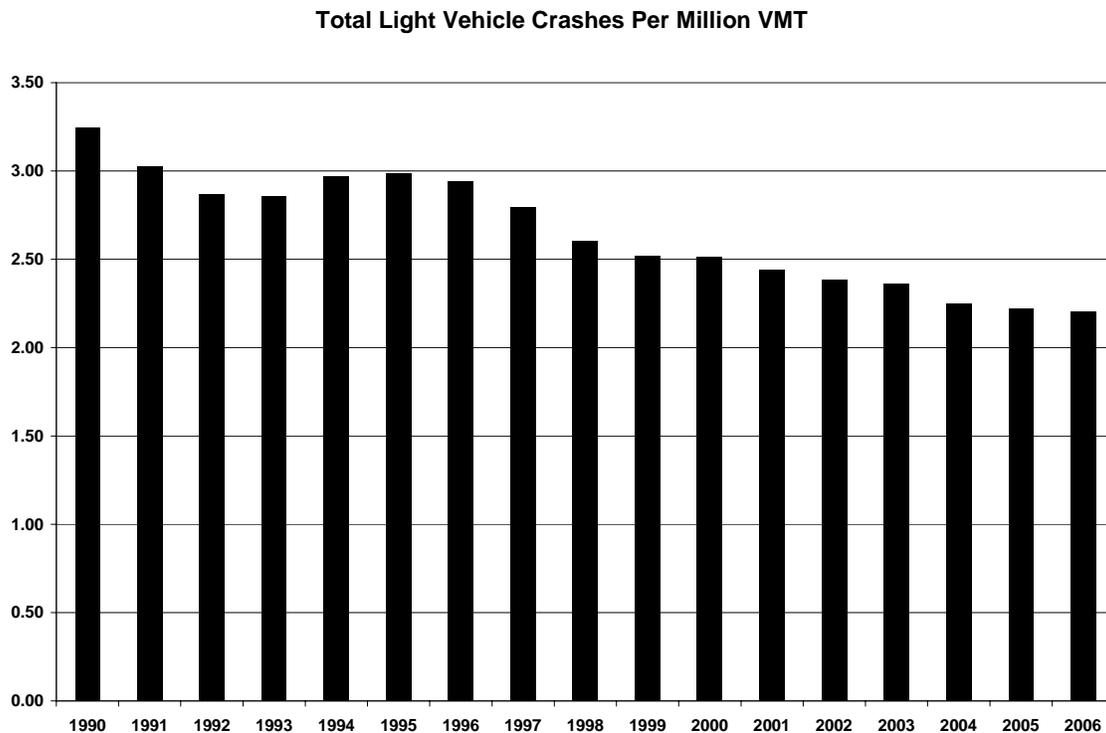
Given these factors, a crash forecasting model would need to take into account the expected growth in VMT (the potential exposure to crashes), along with the general improvement in road safety. Using crashes per VMT as our dependent variable, we can model this structure as:

Crashes per VMT_t = f((crashes per $VMT)_{t-1}$, (technology/safety improvements)$_t$)

Essentially, the current rate of crashes per VMT is a function of the rate in the prior period and improvements in technology that would make driving safer. We would expect the lagged crash per VMT ratio to have a positive influence; in the very short-run, we expect the level of crashes in the next period would be dependent upon the current level. The technology variable should have a negative influence on the crash rate; over time the introduction of new technology should make vehicle travel safer.

A forecast of VMT is available from our VII VMT forecast. This means our crash model will be internally consistent relative to the VMT prediction created in the VII VMT model. To be able to capture the effect of technology and other positive influences on driving safety, such as driver education, we utilized a time trend variable. This is done as there is no readily available over-arching variable that could represent these changes, particularly in technology. Our approach to creating this trend variable begins by assuming that the historical long-term annual average growth rate in the crash ratio is a

reflection of average effect technology is having on crashes per VMT. Between 1988 and 2006, the compound average growth rate for crashes per VMT is -2.73%. The coefficient on the trend variable was estimated at -2.72, representing this historical change. Assuming that the gains from technological advances will moderate over time, a log form for this variable was chosen which will move the crash forecast towards an asymptote.

Based on the above functional form, a regression analysis resulted in the following forecasting equation, which was estimated from 1988 through 2006 (the forecast period is 2007-2055):

$Ln(CR/VMT_t) = 13.74 + -2.72 *   LN(TT_t) + 0.83 * Difference(Ln(CR/VMT)_{t-1})$

Where:
$Ln(CR/VMT_t)$ = Natural log of Crashes per VMT at time $_t$
$Ln(TT_t)$ = Natural log of time trend at time $_t$
$Difference(LN(CR/VMT)_{t-1})$ Change in the natural log of Crashes per VMT at time $_{t-1}$
(All of the independent variables were significant at the 5% level; R bar Sq = 0.967; DW = 1.49)

The forecasted value of crashes per VMT follows a steady downward trend, with growth rates dropping in the outer years of the forecast (Figure 3). This would be consistent with the view that technology advances will eventually have a diminishing effect on travel safety.

Figure B.3:

Crashes Per Million VMT
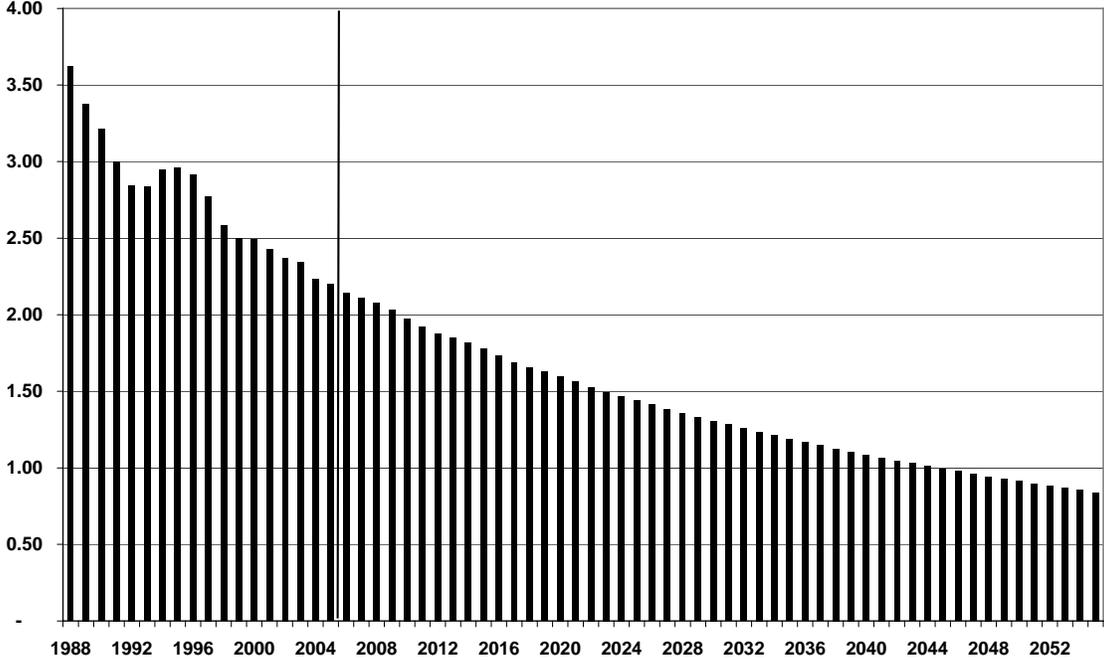
In absolute value, our forecast predicts the number of crashes will level out at around 5 million per year by 2055. With VMT continuing to grow, however, this will continue to represent a falling crash rate.

Figure B.4:

Total Crashes (Light Vehicles)
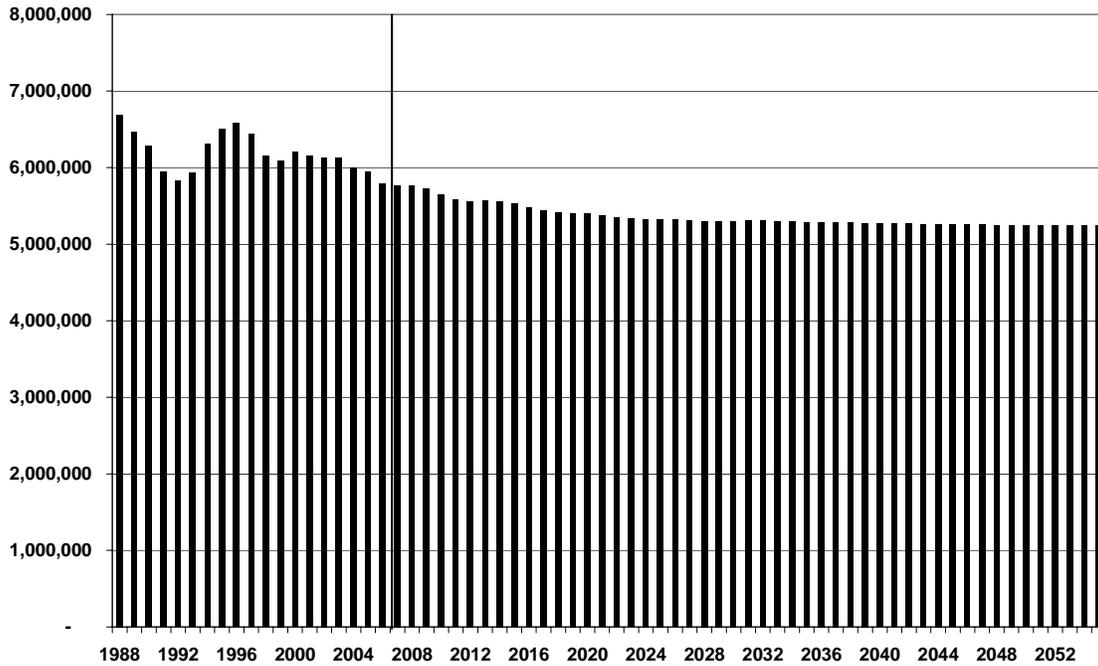
The total crash forecast is then used to drive predictions of crashes for the four scenarios we are looking at within this study. To do this we utilized a "share-down methodology." For example, the average historical ratio of total traffic signal and stop sign crashes to total crashes is used as a constant to allocate the number of forecasted total crashes for a given year that should fall under this lower-level category. Mathematically this is represented as:

Stop Sign/Traffic Signal Crashes$_{t+1}$ = Total Crashes$_{t+1}$ * ((Stop Sign/Traffic Signal Crashes)/Total Crashes)

In this case the Stop Sign/Traffic Signal Crashes/Total Crashes ratio is a constant, derived from the average historical ratio for the period 2000-2006.

This share-down methodology was applied to all of the lower level crash and fatal crash scenarios required for the VII analysis. This approach was adopted as capturing and forecasting a trend at this low level would be difficult. In particular, crashes at this lower level are only a fraction of VMT, which is our primary explanatory variable, making a formal analysis difficult. In addition, we only have VMT available at the macro level, which would not be directly applicable to modeling crashes at individual locations or scenarios. We understand that we are making a simplifying assumption by using this share-down methodology, but believe it allows us to produce a consistent top-down crash forecasting model. As a result, we are assuming that there will be a constant relationship

between these lower level crash scenarios and total crashes throughout our forecast horizon.   After establishing our baseline crash projections we are able to then estimate the number and economic value of crashes that may be avoidable through the introduction of VII.

Estimates of Crashes Avoided from VII Safety Applications

This BCA is focused primarily on the monetization of VII's expected costs and benefits, but in some contexts it may be more useful to think in terms of the <u>number</u> of crashes estimated to be avoided due to VII's safety applications, rather than the economic value of those crashes. Estimates of crash avoidance have been generated for each of four safety applications, using the parameters outlined in Section 5: subject crashes and application efficacy, and where relevant RSE coverage, with each year's figures also adjusted to reflect the gradual rise in OBE presence. As described above, an overall adjustment has also been made to account for the countervailing forces of generally declining rates of light-vehicle crashes but increasing crash exposure (VMT). The table below provides year-by-year detail of the estimated crashes avoided from each of the four applications. The totals rise quickly as more vehicles become OBE-equipped, and later reach something of a plateau due to the fact that OBE penetration has neared 100 percent. In the latter years, the effects of forecast growth in VMT are nearly completely offset by the forecast decrease in the underlying crash rate per vehicle-mile of travel.

The figures in Table B.1 include crashes of all severity levels. In discussions of potential highway safety improvements particular consideration may be given to the number of fatal crashes or fatalities that are estimated to be avoided. Generating such an estimate requires three key additional assumptions:

- The severity distribution of the subject crashes is assumed to remain constant over the project time horizon. (For example, if one percent of the Curve Speed Warning application's subject crashes are fatal crashes, this proportion is assumed to apply throughout the 40-year forecast period, even though the overall number of such crashes will vary over time.) This is roughly consistent with GES data from recent years, which indicates little net change in severity distributions. An average of the subject crashes' severity distributions over the period 2002-2006, as reported in GES, was used here to estimate the severity of future crashes avoided.

- The applications themselves are assumed to have equal efficacy for subject crashes at each point along the severity scale. That is, a 25 percent effectiveness rate is assumed to apply for property damage-only crashes as for crashes involving minor or major injuries or fatalities. This is an area of considerable uncertainty because the safety applications have not yet been field-tested – it is not known whether particular applications tend to be more effective at preventing the most serious or conversely the most minor crashes. This assumption will be revisited once more is known about the real-world effectiveness of the applications.

- In presenting information on the number of fatalities, as distinct from fatal crashes, an adjustment needs to be made for the fact that some of these crashes result in multiple fatalities. An adjustment factor was developed based on the average number of fatalities per fatal crash for each of the four subject crash types, as reported in GES for the period 2002-2006. This factor is also assumed to remain constant over the estimate period.

Based on these assumptions, the overall crash forecasts, and information from the GES crash database, the four VII safety applications analyzed here are expected to prevent significant numbers of fatalities. In the early years of VII deployment, the estimated number grows in line with increasing OBE penetration, ultimately reaching a plateau at around 325 fatalities per year in the 2030s. This is approximately 1.2 percent of the total light-vehicle fatalities forecast for those years. These estimates are inherently tentative due to the nature of the assumptions, particularly with respect to application efficacy, and should be viewed only as a preliminary indication of the rough expected magnitude of the applications' impacts until additional information becomes available from field testing.

Table B.1: Estimated Crashes Avoided with VII.

	Signal Violation Warning	Stop Sign Violation Warning	Curve Speed Warning	Electronic Brake Lights	Estimated Total Crashes Avoided	As Share of Forecast Annual Light Vehicle Crashes
2011	0	0	0	0	0	0.0%
2012	168	41	202	26	436	0.0%
2013	749	182	898	227	2,055	0.0%
2014	1,968	477	2,361	882	5,688	0.1%
2015	4,011	973	4,812	2,359	12,155	0.2%
2016	5,451	1,322	6,539	4,399	17,711	0.3%
2017	6,805	1,651	8,164	6,911	23,531	0.4%
2018	8,098	1,964	9,714	9,826	29,602	0.6%
2019	9,342	2,266	11,206	13,092	35,906	0.7%
2020	10,505	2,548	12,601	16,579	42,233	0.8%
2021	11,550	2,802	13,855	20,122	48,329	0.9%
2022	12,483	3,028	14,975	23,625	54,111	1.0%
2023	13,342	3,236	16,004	27,077	59,659	1.2%
2024	14,140	3,430	16,962	30,443	64,975	1.3%
2025	14,857	3,604	17,822	33,606	69,888	1.4%
2026	15,468	3,752	18,555	36,450	74,225	1.4%
2027	15,961	3,872	19,147	38,883	77,863	1.5%
2028	16,358	3,968	19,623	40,926	80,876	1.6%
2029	16,697	4,050	20,029	42,666	83,441	1.6%
2030	16,990	4,121	20,380	44,148	85,639	1.7%
2031	17,227	4,179	20,666	45,363	87,435	1.7%
2032	17,404	4,222	20,877	46,312	88,815	1.7%
2033	17,530	4,252	21,028	47,041	89,851	1.8%
2034	17,628	4,276	21,146	47,626	90,676	1.8%
2035	17,716	4,297	21,251	48,125	91,389	1.8%
2036	17,794	4,316	21,345	48,549	92,003	1.8%
2037	17,853	4,331	21,417	48,888	92,489	1.8%
2038	17,891	4,340	21,462	49,139	92,833	1.8%
2039	17,915	4,346	21,490	49,328	93,079	1.8%
2040	17,935	4,350	21,514	49,490	93,290	1.8%
2041	17,958	4,356	21,542	49,642	93,497	1.8%
2042	17,979	4,361	21,567	49,779	93,687	1.8%
2043	17,993	4,365	21,584	49,880	93,822	1.8%
2044	17,999	4,366	21,591	49,946	93,901	1.8%
2045	18,000	4,366	21,593	49,995	93,954	1.8%
2046	18,004	4,367	21,597	50,044	94,012	1.8%
2047	18,011	4,369	21,605	50,098	94,083	1.8%
2048	18,018	4,371	21,614	50,147	94,150	1.9%
2049	18,020	4,371	21,616	50,174	94,182	1.9%

Appendix C: BCA Task Force Summary Documents

The following individuals participated in one or more of the Task Force teleconferences. Their valuable input, representing a range of public and private sector perspectives, was extremely helpful in developing and refining the benefit-cost estimates included in this report. Note, however, that these participants have not had an opportunity to review this report. Their participation should not be taken as an endorsement of the report or its findings.

Name	Organization
Valerie Briggs	ITS JPO
Ron Mauri	Volpe Center
Sean Peirce	Volpe Center
Michael O'Mara	Volpe Center
Jim Bunch	Noblis
Joe Peters	Turner-Fairbank Highway Research Center
Scott Geisler	General Motors
Jim Schultz	Michigan DOT
George Gilhooley	Florida DOT
Craig Pickering	Booz Allen Hamilton
Jan Urbahn	BMW
Barb Wendling	Chrysler
Jim Wright	Minnesota DOT
James Pol	US DOT
Tom Schaffnit	Honda
Hideki Hada	Toyota
Sarah Hiple	Nissan
Steve Lockwood	PB
Valerie Barnes	Johns Hopkins
Tim Hsu	Chrysler
Emil Wolanin	Montgomery Co., Maryland
Steve Shladover	Univ. of California PATH
Carlos Lopez	Texas DOT
Douglas Noble	ITE
Wayne Tanda	ITE/Monterey
Gary Piotrowicz	ITE/Oakland Co.
John Fisher	ITE/Los Angeles
David Gerard	ITE/ Austin
Siva Narla	ITE
Ralph Robinson	UMTRI
Al Kosik	TxDOT
Michael Trentacoste	Turner-Fairbank Highway Research Center
Kunik Lee	Turner-Fairbank Highway Research Center
Roya Amjadi	FHWA
Mark Gieske	MN DOT
Ted Trepanier	WSDOT
George Webb	Palm Beach Co.
Ray Starr	MN DOT

VII Benefit-Cost Task Force
October 24, 2007 Teleconference
Topic #1 – Defining the Base Case Scenario

Summary

Discussed parameters and assumptions that make up the "base case" for VII benefit-cost analysis, such as future growth in the vehicle fleet and vehicle-miles traveled (VMT). Task Force (TF) members suggested alternative parameter values, sensitivity ranges, and information and data sources.

Discussion Summary

- o **Population Growth.** It was suggested that growth in the driving age population (rather than total population) might be a better reference point for estimating future travel demand.

- o **Light-vehicle VMT.** Several participants noted that heavy vehicles, commercial fleets, and public transit vehicles may become part of VII and will benefit from Day 1 applications.

- o **VMT Growth.** There was some discussion of the factors that influence VMT (demographics, fuel costs, etc.) and the difficulty in estimating future years. Some nearer-term projections are available from FHWA, and it was suggested that these projections may be more appropriate for the period up to 2024. Others felt that due to the uncertainties involved, the current assumption is acceptable but should be accompanied by a sensitivity analysis. A range of +/- 20% was recommended as reasonable for sensitivity testing.

- o **Congestion Delays and Congestion Growth.** It was observed that congestion delays tend to grow more quickly than VMT, at least at the metro-area level. The TF encouraged Volpe to check for recent DOT documents that might have projections. This is an area where sensitivity analysis would be valuable.

- o **Crashes and Crash Rates.** It was suggested that NHTSA regulatory evaluations and crash rate forecasts be consulted, and that the impacts of vehicle-autonomous systems should be taken into account. It may also be worthwhile to examine data on changes in particular crash types and scenarios. A sensitivity analysis is recommended.

- o **Vehicle Fleet, Sales, and Scrappage.** Although the other assumptions were viewed as reasonable, the 1.5% growth rate for new vehicle sales was viewed as unrealistically high and not in keeping with recent trends. The consensus view was that this rate should be pared back to be closer to the rates used for the growth of fleet and VMT. This will require corresponding adjustments to the scrappage/VMT tables. The overall fleet growth assumption could also be the subject of sensitivity testing since it has a strong influence on total OBE cost.

- o **Emissions.** There were some suggestions to present emissions avoided in physical terms (e.g. tons) as well as in dollar terms. A gradual decline in emissions/VMT is plausible, and it was noted that Dept. of Energy or other projections may be available to enable a specific set of assumptions. Because legislative and regulatory changes will influence emissions, and because fuel sources may change, it was suggested that it may also be useful to analyze the energy content (BTUs) consumed by vehicle travel.

- o **Applications.** Several participants suggested including applications that go beyond the list of "Day 1 applications" in the analysis. Although it is acknowledged that VII will have many other future applications, these will not be included in the current round of benefit-cost analysis, which is designed to support the viability assessment and is based on the application descriptions that have been developed.

Outcomes / Actions

- o The base case assumptions are generally acceptable to the Task Force, but there is sufficient uncertainty about some important variables (VMT and fleet growth, change in crash rates, and relationship between congestion and VMT) that a sensitivity analysis on these variables should be included in the benefit-cost analysis.
- o The assumption on growth in new vehicle sales will be revised downward to more accurately reflect trends in sales. This will entail concomitant revisions to the assumptions about vehicle scrappage.

- o The Volpe Center will continue to gather data and existing forecasts on VMT, crashes and crash rates, fuel economy, and emissions and make the base case assumptions consistent with values used in prior documents where prudent.
- o The VII program (ITS JPO) will work to resolve certain policy questions about equipping transit vehicles and heavy trucks; retrofitting of older vehicles with OBE; backward compatibility of OBE; and future applications beyond the list of "day one" applications. However, this stage of the benefit-cost analysis is designed to support the viability assessment in spring 2008, and not all of VII's future options or capabilities will necessarily be included in the analysis.
- o Times were fixed for upcoming conference calls (see below).

Scheduling

Conference Call – Topic #2 - VII Mobility Applications
- o Monday, Nov. 5, 2 pm ET
- o Read ahead to be distributed Oct. 29

Conference Call – Topic #3 - Safety Applications
- o Wednesday, Nov. 28, 2 pm ET
- o Read ahead to be distributed Nov. 20

VII Benefit-Cost Task Force
November 5, 2007 Teleconference
Topic #2 – Mobility Applications

<u>Summary</u>

Discussed the mobility-oriented "Day One" applications. Task Force (TF) members suggested alternative approaches to defining the applications and provided information and data sources for estimating impacts.

<u>Discussion Summary</u>

- **Scope of Applications:**   Several TF members stated that the current application descriptions are overly narrow and that using them as the basis for analysis would result in significant under-estimation of VII's true benefits. Other TF members expressed a need to remain conservative and credible in the estimates and link the analysis to specific, documented VII use cases.

- **Ramp Metering.** Participants noted that *dynamic* control of the ramp meter timing plans, while not part of the current application description, would produce the largest benefits in terms of traffic flow. On the idea of using VII data to support periodic re-timing, one participant wondered if VII would have much impact, since many transportation agencies do not make much use of the data that they are already collecting. In response, it was stated that VII would allow a comprehensive look at conditions on the whole system (including nearby arterials), not just the ramp and immediate upstream and downstream areas; this would increase the ability to do effective re-timing and also reduce the public opposition to ramp metering that stems from perceptions that it merely shifts traffic to arterials.

  Since VII's probe data would obviate the need for loop detectors in association with ramp metering, this is a potential area for cost saving benefits. According to TF members, loops last for anywhere from 3 to 30 or more years depending on the location, with an average service lifetime of perhaps 10 years. They cost about $1000 to replace (more for new installations) and these costs are one of the factors holding back broader deployment of ramp metering.

- **Traffic Signal Optimization.** As with ramp metering, it was noted that dynamic control is the ultimate aim of VII and would be the greatest source of mobility benefits. Even without dynamic control, however, VII would allow the collection of certain data elements (including actual rather than imputed vehicle speeds and stop/start patterns) that are currently unavailable from loops and that would be useful for doing signal progression and timing. It was noted that loop detectors that are used for signal actuation could <u>not</u> be removed until the vehicle fleet was fully equipped with VII, but other system detectors could be removed once VII was underway. Traffic signal re-timings entail significant costs (about $2500 to $3000 for data collection, plus staff time for analysis). Thus one VII benefit would be the elimination of data collection cost (though not the staff time costs), and thus this could also allow agencies to conduct more frequent re-timing.

  TF members also noted that calculating the mobility benefits from VII-enabled signal timing changes is extremely complex and would be a good candidate for a more in-depth analysis in future phases.

- **Corridor Management.** It was noted that the collection of origin-destination data would be on a strictly <u>opt-in</u> basis due to privacy considerations. This raises the prospect of unrepresentative samples, though arguably no more so (and possibly less) than the current generation of pen-and-paper surveys. TF members recognized the possibilities for enhancing the transportation planning process with a rich store of data from VII. At the same time, it was noted that many agencies do not use the data that are already available and that most long-term planning models cannot necessarily accommodate the types of data that probe vehicles would generate. Eliminating paper O-D surveys would be a major cost savings, though partly offset by the need for a one-time upgrade to the planning models.

  On the idea of using VII data for "load balancing" across nearby or parallel facilities, it was suggested that it is much more likely that this would take place through individual drivers' use of traveler information, rather than through explicit direction from transportation agencies. This allows travelers to make their own decisions and avoids the impression that the agency is directing people onto arterials or local streets.

- **Electronic Toll Collection.** This is another opt-in application due to the inherent privacy and billing issues. There was a discussion of the extent to which VII would actually enable new functions or achieve cost savings. On the one hand, VII would eliminate the need for motorists to purchase a separate device ($10-25) just for tolls, would achieve nationwide interoperability, and would ultimately reduce or eliminate the need for tollbooths or even gantries for ETC. On the other hand, this could require a lengthy and potentially

expensive transition period during which both 5.9 GHz and 900 MHz tags would need to be accepted (and/or retrofit of older vehicles to allow 5.9 GHz toll collection), and it is extremely likely that nationwide interoperability will be achieved fairly soon even without VII. About 65% of toll collection in the US is by ETC at present, and this rate might increase with nationwide compatibility and no need for a separate device. However, would-be ETC users would still have to sign up for an account. Electronic payment in other settings (e.g. parking, fuel) will be discussed during the teleconference on private applications.

- o **Traveler Information, In-Vehicle Signage, and Weather Information:** The major improvement over current information services that VII could provide would be traffic conditions and travel times on arterials, where there is currently little coverage due to the expense of current monitoring equipment (loop detectors, toll tag readers) and message signs. There was general agreement that enhanced traveler information would be extremely beneficial yet very difficult to quantify in terms of changes in travel times and congestion.

  From a cost-savings point of view, it was suggested that state DOTs would begin to think about not replacing their dynamic message signs when VII reached about 50% fleet penetration. TF members did not have any information on weather information or winter maintenance applications of VII.

Outcomes / Actions

- o Estimation of impacts of these mobility applications will be based on a combination of travel time improvements and agency cost savings, as applicable. There are several areas – particularly corridor management and traveler information – where beneficial impacts are expected but quantification will be constrained by a lack of data and/or methods by which to estimate impacts.
- o The BCA report will make note of the envisioned expansion of applications (e.g. to include dynamic signal control), but estimation of these benefits is beyond the scope of the current BCA effort.
- o The BCA team will review NTOC's "traffic signal report card" document for info on signal timing practices and contact TTI regarding their methodology for estimating signal optimization impacts on congestion.
- o A time was fixed for the upcoming Topic #3 conference call and proposed for Topic #4 (see below).

Scheduling

Conference Call – Topic #3 - Safety Applications
- o Wednesday, Nov. 28, 2 pm ET (Scheduled)
- o Read ahead to be distributed Nov. 20

Conference Call – Topic #4 - Private Applications
- o Monday, December 17, 2 pm ET (Proposed)
- o Read ahead to be distributed Dec. 10

VII Benefit-Cost Task Force
November 28, 2007 Teleconference
Topic #3 – Safety Applications

Summary

Overall Approach

It was noted that crash data are limited by the prevalence of non-reported accidents, particularly "property damage only" (PDO) crashes. It was suggested that data on the number and costs of these unreported crashes may be available via AAA or the Insurance Institute for Highway Safety (IIHS).

Once again, there were questions regarding deployment options, particularly the issues of aftermarket parts (retrofitting) and whether VII would be limited to light vehicles. These issues will be addressed via the Deployment Task Force and policy decisions by the ITS JPO. In the near-term, some assumptions will be made for the purposes of benefit-cost analysis that do not necessarily reflect the final plan for VII.

Another suggestion was that, although safety applications are often assumed to be ineffective with intoxicated drivers, there may in fact be some benefits, albeit at a lower effectiveness rate.

One member offered an alternative value for the weighted average cost of a crash at $160,000. This is the figure used by his organization and is based on National Safety Council (NSC) numbers. The BCA has used crash costs that are weighted averages for particular crash scenarios, and ultimately derived from NHTSA estimates.

Signal Violation Warning

The group discussed the assumptions about changes in crash rates over the 40-year analysis period and the extent of RSE deployment coverage at intersections. These assumptions will be reviewed.

It was also commented that the efficacy numbers are among the most important variables to undergo sensitivity analysis. It was suggested that in addition to using the somewhat limited studies currently available, the analysis could employ a panel of crash avoidance experts to evaluate a representative sample of crashes to determine a likely effectiveness range. At the same time, it was noted that there is not likely to be a standard interface, and the HMIs used will most likely be proprietary to the OEMs and vary as such.

 There was some discussion about using a CAMP report that may have some efficacy tools/figures. Some people were opposed to this idea, citing that the authors of the report were uncomfortable with the results.   It was also suggested that the Nissan Sky project in Yokohama, Japan, could have useful information. It was generally agreed, however, that no real "hard data" on effectiveness would be available until the CICAS field operational test is complete.

There was some discussion about retrofitting and what the actual performance of an after-market device would be – i.e. whether it could ever be as effective as an OEM-installed application.

It was suggested that the estimated number of fatalities avoided be presented separately from total crashes avoided and their dollar value.

Incremental Costs

There was some discussion about the separation of OBE maintenance costs and the application costs per OBU.   It was suggested that it may be useful to assign costs to groups of applications which may share the same maintenance tasks (e.g. map maintenance) – e.g., Vehicle-Infrastructure, Vehicle-Vehicle, and Vehicle memory specific applications.

Another point raised was that each application has some level of required updating and maintenance based on changes such as new pavement markings and associated map updates.

Stop Sign Violation

There was discussion about the scope of the application and whether it is feasible to run the application using an area map database, which would not require RSE at each location. If the map database approach is used, this cost needs to

be included either as part of the core VII system or as an incremental cost of this application. It was suggested that maintenance of a stop sign location database could be costly, especially in fast-growing urban areas.

Curve Speed Warning

There was a discussion about whether this application truly offers anything more than what could be achieved using a vehicle-autonomous system and whether it would be useful for the much larger number of road departure crashes that are associated with drowsy or impaired driving. One example of a VII enhancement is the ability to fine-tune the warning based on road weather and traction information from nearby vehicles. It was suggested that the appropriate crash sub-set for analyzing this applications is crashes caused by excessive speed on curves.

Electronic Brake Lights

A "cluster effect" was described whereby the application could be beneficial to multiple vehicles, if one equipped car in the area (not necessarily the immediate following vehicle) brakes in response to EBL, and other cars in the area follow suit. The phase-in of benefits is therefore slightly more complex than simply looking at the probability that any two vehicles would both be equipped at a given point.

Inattention is the key factor in these crashes, and the Virginia Tech "100 car study" was suggested as a good source of data on the role of inattention (distraction) in rear-end crashes and near-crashes.

One participant also asked if the dollar value for rear end crashes avoided included the number of secondary crashes. It does not, but does include the associated travel delays.

Next Teleconferences

December 17 at 2 pm Eastern – Private Applications
January 7 at 2 pm Eastern – Fiscal Impacts

VII Benefit-Cost Task Force
December 17, 2007 Teleconference
Topic #4 – Private Applications

<u>Summary / Outcomes</u>
The call addressed the issue of private sector applications that may use the VII network. In general, antitrust concerns made it difficult for Task Force members to comment on any specific applications, plans, or expected benefits. As such, it is likely that these impacts will be considered only qualitatively in the BCA. However, the BCA team will research the possible benefits of fleet management applications as well as the impacts of customer relationship management in other industries.

<u>Discussion</u>
The call started with a reminder about antitrust principles and a discussion of what constituted a "private" application. The general sense of the group was that a private application is one that is developed by the private rather than public sector, that uses the VII network, and that works on an opt-in basis. As a general rule, most private applications could use alternatives to DSRC because they do not have the low-latency requirements of safety applications.

Private applications could have certain safety or mobility benefits, but they may also have purely commercial benefits in areas such as transactional convenience. There was also a discussion of whether these sorts of benefits and costs are properly part of a public sector analysis. The BCA team stated that they believe all categories of impacts should be considered in a BCA that takes a "societal" approach, and that the Executive Order that requires benefit-cost analysis also requires considering all impacts. Nevertheless, the specific criterion being used for the Viability Assessment gives special weight to the conventional public sector safety and mobility benefits.

The following potential categories of private applications and their associated functions and benefits were discussed:

- Electronic payment (e.g. in-car payment of fast food purchases): primary benefit is transactional convenience

- Remote diagnostics: would help drivers avoid breakdowns and could lower costs of maintenance and repair by catching problems early; could be used by OEMs to develop a database of emerging vehicle issues for early identification of problems

- Customer relationship management: provides benefits to auto customers (and builds loyalty for manufacturers) by providing information and updates to drivers that are fine-tuned to vehicle status, location, etc. Benefits could be difficult to quantify, but there may be information available from applications of CRM in other industries, such as lodging.

- Warranty and repair: using the VII network could help save on recall-related mailing costs; improve the take-up rate for recalls (which could have safety and emissions benefits); and possibly allow for remote repairs.

- Entertainment and downloads: a DSRC system would ordinarily have sufficient bandwidth for audio and video downloads at relatively high speeds. One of the benefits could be convenience, but there is no specific business model and it is not clear that VII is the best means of doing this.

- Navigation: was included in the Proof of Concept testing but is not necessarily a high priority. One area of benefit would be the possibility of automatic updating of navigation maps by driving past RSE rather than periodically loading DVDs.

It was suggested that fleet management should be added to the list – VII could be used to improve on the fleet management programs that already exist. Also, location-based commerce is a concept being used in other fields that combines aspects of electronic payment and CRM.

In general, Task Force members confirmed that there are efforts to pursue most of these categories of applications, but could not comment much further on any specific products or plans. An earlier document listed dozens of potential use cases for VII and could be used as a point of reference.

<u>Next Teleconferences</u>

January 7 at 1 pm Eastern – Fiscal Impacts
January 28 at 1 pm Eastern (tentative) – Deployment Scenario

VII Benefit-Cost Task Force
January 7, 2008 Teleconference
Topic #5 – Fiscal Impacts
Summary

Summary

The task force discussed the merits of having a fiscal analysis in addition to the benefit-cost effort, especially in light on uncertainty regarding an appropriate business model to use. In addition, there was some discussion about performing an analysis of yearly costs/benefits of the entire VII system in nominal terms, giving a more comprehensive view of the fiscal implications without needing to determine on whom the fiscal burden would fall.

Outcomes / Actions

The Volpe Center will not perform a full analysis of the fiscal impacts of VII, but will include an analysis of yearly nominal costs and benefits in the next iteration of the BCA. Upon more concrete decisions from the VII program regarding a business model, it will be more feasible to expand this analysis.

Scheduling

Conference Call – Topic #6 – System Costs
- o Monday, Jan. 28, 12 pm ET (Scheduled)
- o Read ahead to be distributed Jan 22nd

Conference Call – Topic #7 – Deployment Scenario
- o Monday, February 11th, 12 pm ET (Proposed)
- o Read ahead to be distributed Feb 4th

VII Benefit-Cost Task Force
January 28, 2008 Teleconference
Topic #6 – Network and Equipment Costs (Part 1)

Summary

This conference call focused on the unit costs of equipment and network components for the VII system. Feedback was given based on the appropriateness of the costs used in the March '07 report to the current vision of the VII program. The conference call was constrained by time and the balance of the read ahead will be discussed at the next conference call. In addition, it was noted that because of Booz Allen's proximity to the outfitting of equipment, as well as their role in the communication's analysis, it may be useful for Volpe to meet with and discuss some of these elements with BAH.

Discussion

Network Related Costs

Network Backhaul
One – Time Cost $180 million
Yearly Cost $150 million
The discussion of network backhaul costs centered around the BAH report, whether it was appropriate to use the report as it is dated and has a limited scope, and around the assumption of a necessary bandwidth of 40kbps.

One participant noted that the UC Path test, a *moderate traffic* intersection had capacity needs of 50kbps for probe-data only. There was a general consensus that both of these broad issues were in need of more study, however, almost across the board, participants were skeptical that 40kbps was enough bandwidth, even for the probe data public applications.

The appropriateness of the bandwidth is also related to whether there would be RSE-level data aggregation. The current plan to transmit all data through the backhaul and aggregate at the SDN level would strain the bandwidth. It was noted that (depending on the number of snapshots) the data transfer rate would need to be much higher and that the current assumption could be off by at least an order of magnitude.

Actions:
For the near-term, the costs associated with the 100kbps in the BAH Communications Analysis will be used, but Volpe will also follow up with BAH to determine whether the assumptions from the 2005 report need to be updated.

RSE Location Analysis (per SDN) $200,000
The cost for an RSE site-survey for each SDN was discussed, and as a weighted average, the cost was generally accepted. This discussion did raise the question of where the time and labor costs for developing and applying a uniform set of criteria for these site analysis and RSE locations would be accounted for.
Actions:
Follow up with Noblis regarding the costs needed for his recent analysis of Detroit, Orlando and San Francisco.
Assume a one-time $500,000 cost for set up of standards and governance of location analyses.

SDN-ENOC Development Cost (one-time) $15 million
There was little discussion on this cost, and the task force generally accepted this value.
Actions:
There is no further work needed on this cost item for this iteration.

SDN-ENOC Equipment and Installation Cost (one-time) $500,000
The cost of equipping and maintaining the SDN/ENOC facilities was discussed, with some participants questioning the costs involved in equipping the SDNs, as well as the assumption that they would be housed in existing facilities that were noted to already be pinched for space.

Actions:
Follow up with sources who have facilities with similar equipment and capital needs. These may include the BAH ENOC and Detroit/Palo Alto SDNs, existing Traffic Management Centers, and the Volpe ETMS center.

ENOC Facility Cost (rent/lease and incidentals) $400,000

There was some discussion on this cost of expressing it as a one-time capital cost, but the magnitude of the value was generally accepted.
Actions:
The value of $400,000 per year will continue to be used for this iteration barring any new information.

ENOC O&M Costs (annually)
Staffing $4.8 million
Maintenance   10%
There was little discussion on the staffing cost, and the task force generally accepted this value. The yearly maintenance cost for the SDN was noted to be low. It was suggested that a 20% cost/year (or 5-year replacement rate) was more appropriate for the type of equipment in question.
Actions:
There is no further work needed on staffing cost item for this iteration.
The yearly maintenance cost will now be assumed to be 20% of the equipment cost.

Governance Costs (annually) $6.8 million
There was little discussion on this cost, and the task force generally accepted this value.
Actions:
The $6.8 million value will continue to be used for this iteration. There is no further work needed on this cost item for this iteration.

RSE Related Costs

The conference call was time-constrained and thus covered only the costs for the RSE unit, the WiMax unit, and the solar panel. These will be continued during the next conference call.

RSE Production Costs (Post-deployment decision) $6 million
There was little discussion on this cost, as it is inter-related to a business or governance model. For the time being, the task force generally accepted this value.
Actions:
The $6 million dollar cost will continue to be used for this iteration, barring any new information.

RSE Equipment Cost (per unit) $1,000
The cost of a new (as opposed to the older versions by Denso and Technocom - $8,000) RSE at this time is $2,000. This is twice as much as the mass-produced estimate of $1000 from the earlier BCA cost report. The TF accepted the $1000 value as reasonable for VII roll-out.
Actions:
The $1,000 value will continue to be used. There is no further work needed on this cost item for this iteration.

WiMax Equipment Cost (per unit) $1,000
Discussion about the WiMax unit proposed that the unit may be more expensive and that a licensing fee for of bandwidth needed to factored into the cost. It was suggested that a company such as Motorola, which makes WiFi units that are designed for mass use and outdoor exposure, would be able to shed some light on the cost of a similar device for the RSE. The TF view was that we will probably learn that the unit costs will be about $3000 instead of the preliminary estimate of $1000.
Actions:
Follow up with company that makes commercial-grade WiMax for outdoor use for a general cost estimate. An estimated cost of $3000 per unit may be used as an interim value.

Solar Panel Equipment Cost (per unit) $10,000
Discussion on the cost of the solar panel required for rural use was wide-ranging, and did not give a conclusive direction. A similar like-equipment costing would likely be useful in evaluating this value.
Actions:
Identify appropriate power standards for RSE solar panels. Follow up with state/local DOTs to identify vendors of solar panels and get a general cost estimate.

Upcoming Conference Calls

February 11th at 12 noon Eastern – Network and Equipment Costs (part 2)

VII Benefit-Cost Task Force
February 11, 2008 Teleconference
Topic #6 – Network and Equipment Costs (Part 2)

Summary

This conference call is a continuation of the January 28th teleconference on unit costs of the equipment and network components of the VII system. The discussion, and thus this summary, picks up where the previous one left off. Feedback was given based on the appropriateness of the costs used in the March '07 report to the current vision of the VII program.

Discussion

Solar Panel $10,000
Discussion on the cost of the solar panel for RSEs without a readily available power source proposed using a proxy to estimate the cost. There were a number of analogous solar panel uses that were proposed to be used as a proxy, including school zone flashers and highway call boxes.
Action:
Follow up with state/local DOTs for costing information from school zone flashers.

Microwave Com. $10,000
Discussion regarding the cost of microwave communications centered on the existing microwave tower infrastructure. It was noted that because of the necessity of line of sight in using microwave, that there might be some additional costs incurred for relay stations.
Action:
The $10,000 cost will continue to be the value for this iteration, barring new information. The issue of the additional relay stations may be up for discussion during the next conference call (deployment).

RSE Installation Costs
It was noted that this was a cost for which there was some basis in program experience. The existing VII test beds could provide valuable insight into installation labor and equipment needs. In particular, VII California presented a paper at TRB which lists the some of the costs associated with installing their RSEs.
Action:
The associated costs for RSE installation will be revised to reflect program experience via VII California, as well as other VII test beds.

RSE Maintenance/Replacement Costs   10% annually
The previous replacement cost estimates made no distinction between planned (upgrade) and unplanned (failure) replacement. During the conference call, it became clear that these costs should be accounted for separately. Two suggestions were made for the planned replacement rate: 7 and 10 years. The general consensus was that the 7 year rate would be more appropriate for telecommunications technologies. In addition, it was generally agreed that an annual failure rate of 10% would be a reasonable assumption.
Action:
The RSE maintenance/replacement costs will be calculated as separate costs, with a 7 year planned upgrade rate and a 10% annual equipment failure.

On-Board Equipment Costs
Development   ???
Equipment $50/unit
Installation   ???
Maintenance/Replacement   2% annually
The discussion of OBE costs was restricted by antitrust concerns. In the case of the development and installation costs, there was little guidance that could be given in terms of determining an appropriate cost assumption. However, for the equipment and replacement costs, the task force again suggested using similar electronics as a proxy.
Action:
A cost estimate will be developed using consumer reports of other onboard electronics such as integrated nav. systems, telematics and satellite radios.

Application Development Costs
Cost Estimate   10,000,000 each

It was noted by the task force that these post-decision costs would be difficult to estimate, especially in the case of the applications that would be model-specific or need bus connections as costs would vary across OEM and across models. Two elements of this development cost were mentioned as the cost of increased OEM internal review as well as NHTSA external evaluation

Action:

Barring new information, the $10 million cost per application development will be used for the next iteration.

Upcoming Conference Calls

The next and final conference call on topic 7: VII Deployment Scenario, was not scheduled during this teleconference, and will be scheduled via email at a later date.

VII Benefit-Cost Task Force
March 13, 2008 Teleconference
Topic #7 – Deployment Scenario

Summary

This call was the Task Force's final teleconference, and focused on the VII deployment scenario and timetable. It was agreed that no final decisions have been made regarding VII's deployment. However, certain assumptions have been made for the purposes of enabling a revision to the benefit-cost analysis. These assumptions were discussed: decision date, RSE deployment period and schedule, OBE deployment, and applications.

Discussion

- It was noted that a separate analysis is underway that is examining possible deployment scenarios and business models, but that some assumptions need to be made now. The BCA revision currently being prepared will not assume any retrofitting or aftermarket OBE, and will consider light-duty vehicles only. This might be referred to as the "minimum deployment."

- The BCA will assume a deployment decision date of 2010, which was viewed as reasonable by the Task Force.

- RSE deployment is assumed to take place from 2011-2015, which the Task Force viewed as probably a best guess at this time. Some members of the group expressed a belief that urban areas would be the first to have RSE deployed, while others cited the difficulty in working with multiple local governments and suggested that interstate highways would be equipped first. In either case, having everything equipped within five years may be optimistic. It was suggested that the deployment be stretched out.

- Installation of OBE is assumed to take place from 2012-2015, with a gradual phase-in on new vehicles (i.e., 25% in 2012, 50% the next year, and so on). The Task Force viewed this as a reasonable estimate and noted that it allows for one year of RSE deployment (in 2011) to take place before any OBE installation to reassure automakers of the commitment to VII.

- VII System characteristics: JPO documents will form the basis of most assumptions about quantities of RSE and the options for electric power and telecommunications. However, it was suggested that at urban intersections, WiMax will be more common than wireline communications (perhaps 10-20% wireline availability based on the California experience), and that urban highways will also primarily use WiMax, though some locations (again, about 20%) will have wirelines available. Also, VSAT may be more cost-effective than microwave for rural RSE. It was mentioned that some urban locations may require "gap filler" (non-intersection) RSE to keep the data delay down to the 2-minute threshold, but that no specific figure is available.

- Applications: the set of applications included in the BCA will be the same (and with the same scope) as discussed in earlier Task Force calls. The "Day One" terminology will be removed to avoid confusion. Most applications are assumed to be ready in 2011, with advance warning info and traveler info in 2012, and corridor management and signal timing in 2013. These dates refer simply to the estimated dates by which the application software will be complete and functionality available. Benefits in any given year will still be a function of the number of equipped vehicles and locations. It was suggested that CAMP is a source of information on some vehicle-to-vehicle applications being developed.