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Vehicle-Infrastructure Integration (VII) Initiative

Benefit-Cost Analysis: Pre-Testing Estimates

Draft Report

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Report for:

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Executive Summary

The Vehicle-Infrastructure Integration (VII) initiative is an ambitious concept that seeks to bring about substantial improvements in safety and reduction in delays 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. 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. At this point, the basic understanding is that if VII were to proceed, the public sector would be responsible for equipping the roadways, most likely through a federal-state partnership, and the automakers would be responsible for equipping the vehicles.

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 $3-4 billion that would be mostly spent in a four year period. Installing VII equipment and systems on all vehicles sold in the U.S. will average over $1 billion per year simply because so many vehicles are involved. A decision to go forward with the VII initiative must consider whether expected benefits justify these costs. Thus, the ITS Joint Program Office commissioned a benefit-cost analysis (BCA) of the VII initiative and this repot summarizes the initial findings.

The BCA involves a systematic and comprehensive quantification of costs and benefits over a program or project life-cycle. It uses a well-accepted procedure for "discounting" values in future time periods to "present values," and a comparison of the present value of costs and benefits is used to judge the potential worthiness of the endeavor.

The benefits of VII stem from the various safety and mobility applications it enables. A set of 14 "Day One" applications have been identified by the public-private Working Group that is planning the VII initiative. A valuation of the expected benefits from these applications has been performed for a 40 year period. The present value sum of the benefits from seven of the applications is $45.7 billion. Not enough information was available to estimate the benefits of the other seven VII Day One applications.

The present value of the costs of implementing VII, including initial infrastructure costs, on-board vehicle equipment, and all operations and maintenance costs, is $16.3 billion.

Thus it is estimated that, when looked at from a societal perspective, the VII initiative will generate net benefits of about $24.9 billion. The ratio of benefits to costs is 2.8 to 1. An initial round of 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 fairly robust.

The results cited are for a base case and were prepared without information from Proof-of-Concept (POC) testing and Field Operation Tests (FOT) planned for later in the year 2007. Thus these results are considered preliminary and will be updated as better information becomes available.

I. 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 reduction in delays 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 all 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 all major roadways to provide communications links between vehicles and the roadways.

With this basic infrastructure in place, any number of specific applications could be enabled. 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, the basic understanding is that if VII were to proceed, the public sector would be responsible for equipping the roadways, most likely through a federal-state partnership, and the automakers would be responsible for equipping the vehicles.

Purpose of this Report

This report has been sponsored by the ITS Joint Program Office. Its purpose is to provide a comprehensive accounting 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. This analysis also provides information on the benefit-cost profiles of individual applications that might be enabled by VII. This application-specific information can be used in deliberations regarding the prioritization of investments in applications based on the scale of expected net benefits.

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 and 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.

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 Approach and 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 have been incorporated into the body of this report wherever possible, though some suggestions may require additional analysis. It is expected that this draft report will also be reviewed by Working Group members for additional feedback.

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.

Proof-of-Concept (POC) tests and field operational tests (FOTs) for VII are planned for 2007 but have not yet been conducted, and most of the potential VII applications are still in the early stages of development. 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, including the POC and FOT results.

This report summarizes an initial BCA conducted based on the information that was available through early 2007. It is by no means intended to serve as the definitive analysis of VII's benefits and costs, but rather as a springboard for dialogue and collaboration with the VII community on these topics.

II. 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.

Full details of the core variables, including the rationale for their selection, potential alternatives and sensitivity cases, are available in a separate report.[1] This section provides a brief overview.

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 2006.

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. 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.

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 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.

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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.

[2] Emil H. Frankel, "Revised Departmental Guidance: Valuation of Travel Time in Economic Analysis," USDOT- Office of the Secretary of Transportation, February 11, 2003.

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 that are based only on the direct costs of the crash (such as medical expenses) and estimates of the foregone earnings or productive capacity caused by the injuries.

In line with USDOT guidance on this topic,[3] the BCA uses $3.2 million as the value of preventing a transportation fatality. Non-fatal injuries are valued according to their severity using the Abbreviated Injury Scale (AIS) and fractional values that are pegged to the $3.2 million figure. These 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). Where appropriate, calculations of crash costs also include a standard estimate of the value of the associated travel delays, for example from congestion related to vehicle clearance at the crash site.

Vehicle Fleet and Sales

The number of light-duty vehicles in use in the U.S. in 2004 was about 234 million and is assumed to grow at 0.8 percent annually throughout the project time horizon; this rate is slightly faster than the expected rate of population growth. New vehicle sales are the sum of fleet growth plus projected scrappage, i.e. the retirement of old vehicles. The number of new light-duty vehicles added to the fleet each year is about 16 million in 2006 and gradually increases to 31 million in year 2050. Scrappage rates vary by vehicle age and are addressed in Section III.

Fuel and Vehicle Operating Costs

Vehicle operating costs are estimated at $1,352 per 10,000 vehicle-miles traveled. 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 the 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).

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

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[3] "Revision of Departmental Guidance on Treatment of the Value of Life and Injuries,” USDOT, Office of the Assistant Secretary for Transportation Policy,

$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 to $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.

III. VII Network Implementation and Costs

As noted above, the VII vision calls for dedicated roadside units to be installed along most major roads in the U.S. and for onboard equipment to be installed in all new vehicles (though initially only in light-duty vehicles). VII implementation will take years to accomplish, and accordingly, VII is planned as a multi-year, multi-phase effort.

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 (in general) 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 information in this section is taken from the most current information available from the VII initiative about the implementation dates for roadside and onboard equipment.[4]

On-Board Equipment – Deployment Schedule

The VII initiative is currently operating on the assumption that VII onboard equipment (OBE) would be installed on *all* new light-duty vehicles produced for the US market after a given date under a partnership agreement with the automakers. That is, the OBE would become standard equipment rather than an option that could be chosen by vehicle purchasers for an additional cost. As such, the calculations of OBE penetration do not take into account models of consumer behavior at different price-points and levels of perceived value, but instead are based directly on the VII program's implementation assumptions.

At present, the VII initiative posits that OBE will be installed on new light vehicles during a three-year phase-in period beginning in 2011. In other words, approximately one-third of *new* vehicles produced in 2011 would have the required OBE, then two-thirds in 2012 and all new vehicles in 2013 (see Table 1). This transition period is designed to allow automobile manufacturers time to adjust the design and engineering of all of their vehicle models to accommodate the new equipment.

Table 1. Assumed Deployment Schedule for VII Equipped Vehicles

	2011	**2012**	**2013**	**2014 and beyond**
Share of <u>new</u> light vehicles with installed VII OBE	33%	67%	100%	100%

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

Note that these assumptions refer only to *new* vehicles. The current VII program plan does not envision retro-fitting older vehicles with the necessary equipment. Therefore, previously manufactured vehicles without the OBE will continue to be driven on America's roadways for many years after 2011, 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 IV.)

To account for this adjustment period, the BCA team referred to data on vehicle longevity that are collected by the R.L. Polk Company's National Vehicle Population Profile and the National Highway Traffic Safety Administration.[5] These data show the likelihood that a vehicle of a given age will be scrapped during that year.

To create a full model of OBE penetration of the U.S. light vehicle fleet over the project timeframe, the NHTSA data were combined with the VII program's assumptions about the phase-in of OBE among new vehicles as well as several assumptions about the light vehicle fleet. These assumptions included a total light vehicle population of approximately 241 million in 2006 (adjusted from the 2004 BTS count), with growth in the on-road fleet of 0.8 percent per year (net of scrappage). In line with recent sales data, new light vehicle sales were assumed to be 16 million in 2006, with growth of 1.5 percent per year.

Based on these assumptions, 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 the assumptions, the number of non-equipped vehicles begins to fall as new vehicles become equipped starting in 2011; the fleet reaches the 50-50 point around 2019. 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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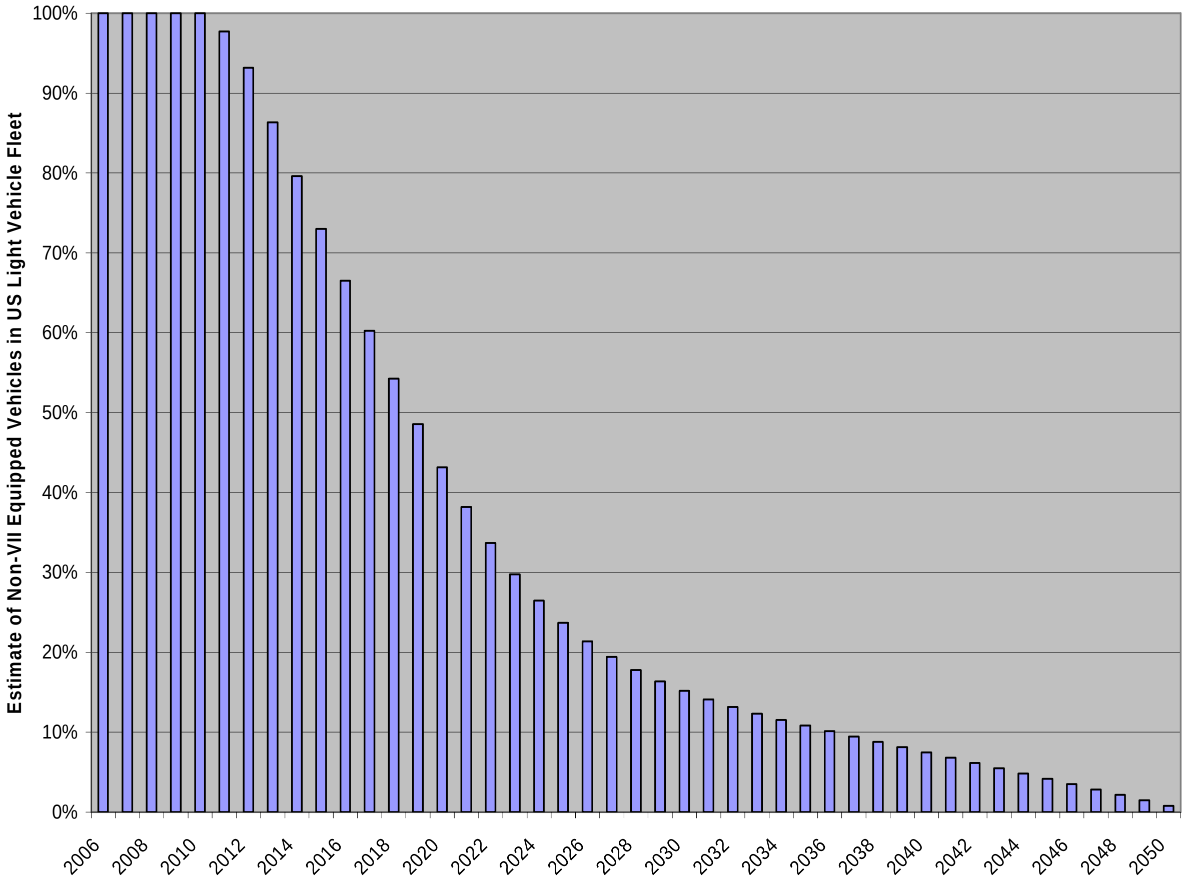
[5] S. Lu, "Vehicle Survivability and Travel Mileage Schedules," NHTSA Technical Report DOT-HS-809-952, January 2006.

Chart 1. Projected Phase-Out of Non-VII Equipped Vehicles in the US Fleet



A further refinement that is needed for most calculations of benefits (though generally not for costs) is to look at 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 derived 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.

NHTSA also reports on the average number of miles driven for vehicles of each age, which is derived from information collected by the Department of Energy's Residential Transportation Energy Consumption Survey. As an example, a new passenger car is driven on average just over 14,600 miles per year, while a 13-year-old passenger car is driven on average about 8,500 miles per year. These data were used to make an adjustment to the OBE penetration figures above based on VMT per vehicle. Extrapolation was used to provide VMT figures for vehicles more than 20 years old, which is the limit of the NHTSA data, and small adjustments were also made to the mileage totals to keep the model internally consistent in out-years. Overall light-vehicle VMT was assumed to grow at 0.8 percent annually from a base of 2.76 trillion in 2006.

When this VMT adjustment is made, the drop-off in non-equipped vehicle miles is slightly more pronounced than that of vehicles . The fleet reaches the 50-50 point in terms of miles traveled by equipped and non-equipped vehicles just before 2018.

On-Board Equipment – Cost Estimates

The basic components of VII's OBE are a positioning device, such as a Global Positioning System unit, a DSRC radio for communication, and a processing unit for data. The OBE would also include some form of driver interface that would convey information to the driver in a safe and usable format, possibly including a mixture of audible, visual, and tactile warnings, depending on the specific VII application.

Cost estimates for this OBE are still preliminary. 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. Based on this estimate and on informal communication with automotive engineers, this BCA uses a figure of **$50** per vehicle as an overall estimate of the upfront capital cost of installing the OBE on a new vehicle at the assembly line, including the hardware and software components and the connections to other vehicle systems. (The issue of the extent to which this cost would be absorbed by the automakers or reflected in the final purchase price of the vehicle is important in some contexts, but does not affect the results of a "societal" BCA such as this one.)

The ongoing maintenance costs associated with keeping these units in working order, as well as providing for any necessary software updates, is not yet known. An initial estimate is **$1** per year for each unit of OBE in operation. This is based on the assumption of a 1 percent annual failure rate and a repair cost double the initial $50 cost of the OBE (or, equivalently, a maintenance cost equal to 2 percent of the installation cost per year), which is a reasonable, albeit approximate, estimate that is roughly consistent with the maintenance costs of other electronic components .

By combining these cost estimates with the fleet penetration figures generated above, total OBE costs can be generated for each year in the project horizon. More specifically, in any given year, the capital costs for OBE will be equal to the per-unit installation cost multiplied by the number of vehicles produced and sold in that year. The operations and maintenance (O&M) costs will be equal to the per-unit O&M cost multiplied by the total number of vehicles – new and old – in the on-road vehicle fleet that are equipped with OBE. The table below summarizes these calculations.

Table 2. OBE Costs by Year (in constant 2006 dollars)

	2010	2011	2012	2013	...	2049	2050
VII-Equipped Vehicles Sold (000)	0	5,716.8	11,663.4	17,757.5		30,805.3	31,267.4
OBE Production & Installation Costs ($Millions)	$0	$287.3	$583.2	$887.9		$1,517.5	$1,540.3
On-Road Fleet of VII-Equipped Vehicles (000)	0	5,716.8	17,281.6	34,811.3		339,617.9	344,713.3
O&M Costs of OBE ($Millions)	$0	$5.7	$17.3	$34.8		$339.6	$344.7

Roadside Equipment – Deployment Schedule

The VII program has proposed a multi-year implementation schedule for roadside equipment (RSE) and the related telecommunications infrastructure.[6] Although this schedule is currently an unfunded plan, it represents the baseline assumption for RSE deployment and is used in calculations here. The schedule includes a set of one-time, upfront cost elements such as research and development, and is then followed by the deployment of individual roadside units over a five-year period. For the purposes of this cost estimate, the upfront costs are assumed to take place in 2008 and the deployment to take place from 2009 to 2013. An additional simplifying assumption is that installation of RSE proceeds "evenly," that is with a roughly equal number of units installed during each year, rather than with significant ramp-ups and ramp-downs of activity.

Roadside Equipment – Cost Estimates

According to the VII program's cost analysis, upfront cost elements include $6 million in development funds to achieve unit-cost reductions in roadside units and $15 million for development and qualification of software associated with the Service Delivery Node (SDN) and Enterprise Network Operations Center (ENOC). Another non-recurring cost is the need for a deployment analysis for RSE in each state and metro area – i.e. determining where to place RSE based on traffic patterns, crash statistics, and road geometry. This is estimated at $200,000 per analysis for each state and each of the 452 metro areas, for a total of just over $100 million. Finally, there is a non-recurring cost of approximately $181 million (as estimated in the Communications Analysis report of July 2006) for backhaul telecommunications capacity. Overall, upfront costs are estimated at $302,400,000.

Each roadside unit involves initial production costs and ongoing maintenance costs. Moreover, in order for the units of RSE to form a coordinated nationwide network and

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[6] W.S. Jones, "VII Life Cycle Cost Estimate," December 2006, USDOT – ITS Joint Program Office.

for the data they collect to be available, the RSE in each metro area and state must be linked to the telecommunications backbone and connected to their SDN. The overall system would be managed through a national ENOC.

Construction and networking costs for the ENOC, the national "command center" for VII, are estimated at $500,000. An additional $500,000 would be required for a backup center to be built at a remote location. Each metro area and state would also require a SDN at a cost of $500,000 each, for a total of $251 million.

The VII deployment plan calls for a total of 252,000 RSEs to be installed over a five year period. The bulk of these (210,000) would be placed at intersections and other urban locations, while 25,000 RSEs would be located on interstate highways and other freeways and 17,000 on other National Highway System (NHS) routes.

Deployment of RSEs at specific locations involves several distinct cost elements: the production cost for the equipment itself, the costs of actually installing the RSE at the site, the costs associated with a connection to a traffic signal (where applicable), and the cost of linking the RSE to the telecommunications system. These costs vary by location due to the types of telecommunication links available in the area. The cost estimate also assumes that some rural locations will lack electrical power and therefore will require solar panels and related electronics at a cost of $10,000 per roadside unit. Additional details on the cost elements can be found in the cost estimate produced by the VII program.

Annual operations and maintenance costs for the RSE have been estimated at just over $176 million. This includes roughly $16 million for staff salaries and facilities costs at the governance body that would oversee the network and the two ENOCs, plus annual backhaul telecommunications costs of approximately $147 million (assuming the use of 40 Kbps lines). Each RSE is estimated to have average annual maintenance costs in the range of $50 per year (i.e., a 5 percent failure rate and $1,000 production cost), for a total of $12.5 million per year across the whole RSE network.

Table 3. VII Network Costs: Roadside Equipment (RSE) and Related Items (Dollars, 2006 Prices)

Development Costs

Item	Quantity	Unit Cost	Total
SDN / ENOC development	1	$ 15,000,000	$ 15,000,000
One-time R&D for RSE	1	$ 6,000,000	$ 6,000,000
Deployment analysis for RSE	502	$ 200,000	$ 100,400,000
Non-recurring backhaul costs	1	$ 181,000,000	$ 181,000,000
TOTAL Development			**$ 302,400,000**

Deployment Costs

Item	Quantity	Unit Cost	Total
Enterprise Network Ops Ctr (ENOC) Main and Backup	2	$ 500,000	$ 1,000,000
Service Delivery Node (SDN)	502	$ 500,000	$ 251,000,000
RSE Installation - Intersections:			
Landline			
Production		$ 1,000	$ 157,000,000
Installation		$ 4,800	$ 753,600,000
Local Signal Connection		$ 1,000	$ 157,000,000
Wi-Max			
Production		$ 4,000	$ 212,000,000
Installation		$ 9,600	$ 508,800,000
Local Signal Connection		$ 1,000	$ 53,000,000
RSE Installation - Metro Freeways			
Production		$ 4,000	$ 72,000,000
Installation (Wi-Max)		$ 9,600	$ 172,800,000
RSE Installation - Rural Freeway / National Highway System Routes			
With existing electric power			
Production		$ 1,000	$ 4,800,000
Installation		$ 4,800	$ 23,040,000
With no electric power (solar)			
Production		$ 1,000	$ 19,200,000
Installation		$ 4,800	$ 92,160,000
Solar panels / electronics		$ 10,000	$ 192,000,000
Microwave telecom for rural RSE			
Production		$ 20,000	$ 480,000,000
Installation		$ 4,800	$ 115,200,000
TOTAL Deployment			**$ 3,264,600,000**

RSE / Network Operations & Maintenance Costs

Cost Element	**Estimated Annual Cost**
Governance - staff & facilities	7,200,000
ENOC operations – main	4,600,000
ENOC operations – remote	4,800,000
Infrastructure maintenance	12,500,000
Communications (40Kbps lines)	147,000,000
TOTAL RSE O&M Costs (Annual)	176,100,000

Summary of RSE and Network Costs

Development Costs	$ 302.4 million
Deployment Costs: ENOC, SDNs, RSE Production & Installation	$ 3.26 billion
Operations & Maintenance	$176.1 million per year
TOTAL in Present Value (40-Year Project Horizon, Discounted to 2006 Values at 7%)	$4.67 billion

IV. 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 subset of potential applications will be analyzed*: the so-called "Day One" applications identified by the VII Working Group. These applications have been identified as those that would potentially be ready to function on the first day of VII's operation.

The Day One applications that have been identified to date are as follows:

- 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
- Probe-Based Mapping
- Private Original Equipment Manufacturer (OEM) Applications

If additional applications are identified as candidates for "Day One" deployment, they may be included in future updates of this benefit-cost analysis.

Overview of Benefit-Cost Estimation for Applications

Each of the Day One 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 as well as a set of documented assumptions. In some cases, estimation has simply 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 straight crossing path 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, even if it were to operate flawlessly in all circumstances.

- 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 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.)

- The estimate of crashes avoided is then split out into severity groups according to assumptions about the severity of these crashes. In general, the assumption is that the crashes avoided are similar in severity to subject crashes as a whole, though this assumption can be relaxed as more information becomes available about the impacts of the application. 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. 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 III, this is based on the share of overall VMT by equipped vehicles, since crash exposure is roughly proportional to miles traveled.

A second adjustment comes into play for those applications which 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 impacts must be scaled down to reflect the relative presence of RSE at each point. The mechanics of this adjustment varies by application.

- 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 terms by the application of the 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 of 0.8 percent per year. However, this adjustment is not used for crash-reduction benefits, because the effects of historically decreasing per-mile crash rates would tend to balance out any growth in VMT.

A similar approach can be taken for estimating and monetizing the 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, which can then be translated into changes (positive or negative) in the emission of several categories of pollutants, such as carbon monoxide and particulates. Computer models are ordinarily used for these calculations, as 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.

For BCA purposes, these models' outputs, expressed in tons of emissions reduced, would then be monetized by applying economic values specific to each pollutant; specific values are discussed in the Core Variables report. This first round of the BCA <u>does not</u> include the value of any emissions reductions or other environmental benefits, simply because sufficient information for these complex calculations is not yet available for any of the

Day One applications. In general, the environmental impacts of VII applications are *expected* to be positive because smoother traffic flow and reduced congestion generally lead to less vehicle idling, cleaner-burning engines, and reduced fuel consumption and vehicle emissions. This supposition can be tested in future rounds of analysis.

Day One 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 straight crossing path crashes involving light vehicles at signalized intersections, where the cause is signal violation. According to analysis of crash databases,[7] these crashes total roughly 178,000 per year; this total excludes cases of driving under the influence (of drugs or alcohol) or driving while intoxicated on the grounds that these types of crashes are not likely to be addressed by the application.

- The efficacy of the application – i.e. its ability to actually prevent a subject crash at an equipped intersection – is estimated at 28 percent based on previous research on related types of countermeasures for the signal violation problem.[8]

- 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 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 intersection. The VII program is estimating that 50 percent of urban intersections

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[7] W. Najm, J. Smith, D. Smith, “Analysis of Crossing Path Crashes,” NHTSA Report DOT-HS-809-423, July 2001.

[8] L. Barr, M. daSilva, J. Hitz, “Safety Benefits/Cost Assessment of Potential IVI Safety Systems,” Volpe National Transportation Systems Center, Project Memorandum, September 2000. The figure cited refers to the infrastructure-based intersection countermeasures, scenario 2 (a form of "red light hold" at signalized intersections).

would be equipped and that these intersections account for 83 percent of intersection crashes.

- In the absence of more fine-grained data on the severity levels of the crashes that would be avoided by the use of the application, a figure of $54,970 is used to monetize the value of the crashes avoided. This is a composite figure for all crossing path collisions involving light vehicles and is a "comprehensive" figure that includes not only direct economic costs but also injury values and travel delays associated with the crash.[9]

On the cost side, this application requires the use of the VII network, the costs of which have been fully accounted for in Section III and are not double-counted here, as well as research and development for the application itself. In keeping with standard practice in benefit-cost analysis, these 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, they would be incurred whether or not the investment in VII ultimately is made or not.

Another cost element is the *incremental* operations and maintenance (O&M) cost associated with running this application using the on-board equipment – the additional costs of maintaining the OBE and RSE in good working order each year. One approach is to assume that the application does not really have any incremental O&M costs, and that any maintenance costs are already captured in the OBE and RSE maintenance cost estimates. An alternate viewpoint is that, just as each application installed on a personal computer adds slightly to the chance that repairs or software upgrades will be needed, so does each VII application add slightly to the maintenance cost of the equipment. To be conservative, therefore, this analysis assumes that each safety application entails an incremental O&M cost for software updates and repairs that are related to this application alone. One-tenth of the assumed $1.00 annual average O&M cost of the OBE alone, or 10 cents per equipped vehicle per year, is used.

Based on the assumptions detailed above, over the course of the project lifetime this application is estimated to yield safety benefits of $12.9 billion in present-value terms, with incremental costs totaling $154 million. Net benefits would therefore be approximately $12.7 billion.

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

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[9] Barr, daSilva, and Hitz, op. cit.

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 straight crossing path crashes involving light vehicles at stop sign-controlled intersections, where the cause is signal violation. Analysis of crash databases[10] indicates that these crashes number about 62,000 per year, again excluding cases involving intoxicated drivers.

- The efficacy of the application is estimated at 38 percent based on previous research in this area.[11]

- 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 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.

- A value of $54,970 is used to monetize the value of the crashes avoided. This is a composite figure for all crossing path collisions involving light vehicles and is a "comprehensive" figure that includes not only direct economic costs but also injury values and travel delays associated with the crash.[12]

Estimates of the incremental costs of this application follow the reasoning described above for signal violation warning: sunk costs of development and testing are excluded, but each new safety application is assumed to entail a small incremental operations and maintenance cost for the OBE. A value of $0.10 per equipped vehicle per year is used for this application as well.

Total safety benefits for this application are estimated at $7.3 billion in present-value terms. Incremental costs are estimated $154 million, meaning that net benefits would be in the range of $7.2 billion.

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[10] Najm, Smith, and Smith, op. cit.

[11] Barr, daSilva, and Hitz, op. cit. The figure chosen reflects the estimate for infrastructure-based intersection countermeasures (all scenarios).

[12] Barr, daSilva, and Hitz, op. cit.

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, given the weather conditions. The system can be designed to receive the information from RSE or to use the on-board sensors and 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. The road condition data is also used in this process.

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:

- Based on research[13] on an alternative form curve speed warning – namely, a road departure warning with similar aims but a different underlying technological approach – the number of crashes that might be prevented by this safety application is estimated at between 20,000 and 49,000 per year.

- 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 value of avoiding a road departure crash is assumed to be $60,870, which is a weighted average across severity levels and includes economic costs, injury values, and crash-related congestion costs.[14]

- The calculations assume the use of the on-board approach mentioned above, in which case the presence of a roadside unit is assumed to be unnecessary. The impacts and benefits have not been adjusted based on RSE presence, although this assumption will be revisited as more information becomes available on application design.

Estimates of the incremental costs of this application follow the reasoning described above: sunk costs of development and testing are excluded, but each new safety application is assumed to entail a small incremental operations and maintenance cost for the OBE of $0.10 per onboard unit per year.

Depending on whether the lower (20,000 per year) or higher (49,000 per year) estimate is used for potential crashes avoided, total safety benefits for this application range from

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[13] B. Wilson, M. Stearns, J. Koopmann, C. Yang, "Evaluation of a Road Departure Warning System," Final Draft Report, USDOT – Volpe National Transportation Systems Center, April 2006.

[14] Barr, daSilva, and Hitz, op. cit.

$6.9 billion to $16.9 billion in present-value terms. In either case, incremental costs total $154 million. Estimated net benefits thus range from $6.8 billion to $16.8 billion. To be conservative, the lower value is used in the summary table below for the base case.

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 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:

- Based on research on another form of rear-end collision warning system,[15] the number of rear-end crashes that would be avoided is 133,000 per year.

- 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 value of avoiding a rear-end crash is assumed to be $31,605, which is a weighted average across severity levels and includes economic costs, injury values, and crash-related congestion costs.[16]

- Calculations assume the use of the on-board approach mentioned above, 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. Again, this assumption will be re-visited as necessary.

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[15] W. Najm, M. Stearns, H. Howarth, J. Koopmann, and J. Hitz, “Evaluation of an Automotive Rear-End Collision Avoidance System,” NHTSA Report DOT-HS-810-569, March 2006. This report estimated the potential rear-end collisions avoided as between 133,000 and 687,000 per year. The safety system being evaluated in the report was a combined Adaptive Cruise Control – Forward Collision Warning, which appears to be more robust that the Electronic Brake Lights application; therefore only the *lower* bound of the estimate range is used in this analysis.

[16] Barr, daSilva, and Hitz, op. cit.

Estimates of the incremental costs of this application follow the reasoning described above: sunk costs of development and testing are excluded, but each new safety application is assumed to entail a small incremental operations and maintenance cost for the OBE of $0.10 per onboard unit per year.

Safety benefits for this application are estimated at $17.3 billion in present-value terms, with incremental costs of $154 million. Net benefits would be approximately $17.2 billion.

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. At present, however, the VII Working Group has described the application more narrowly: VII-supplied probe vehicle data would be used for periodic 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. As such, the expected future benefits of this application were calculated as an improvement over existing benefits.

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 2005 Urban Mobility Study, the use of ramp meters produces an annual reduction in travel delays equal to 102 million person-hours. This figure is for the nation's 75 largest metropolitan areas, and most of the total comes from a handful of large conurbations that make extensive use of ramp metering. How much *additional* benefit could be obtained by using VII data to periodically improve the signal timing plans? There is no definitive answer to this question, but 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.[17]

Based on these research findings, and as a first approximation, a 5 to 10 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 about 5 million to 10 million person-hours per year. In producing calculations for future years, no adjustment has been made for differing levels of OBE penetration; this is based on the assumption that optimization can take place using data from even a relatively small number of probe vehicles. In other words, even if only a small share of the vehicle fleet is equipped, these are sufficient to serve as probes of overall traffic conditions, and 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 0.8 percent per year, since additional vehicle traffic translates into additional potential for delay reductions.

These 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 II and is therefore used in the absence of more fine-grained information on the impacts on local versus long-distance vehicle travel. (Adjusting VOT based on location may be part of subsequent analyses.) This calculation yields mobility benefits in the range of $59 million to $119 million per year in the first year of operation, growing thereafter due to VMT growth and additional RSE deployment.

The 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 signal – something that state and local DOTs do anyway for their ramp meters. There is very little incremental cost aside from some start-up issues associated with developing the software to translate raw RSE data into a usable format. In fact, the VII network potentially offers a source of cost savings in this area, since VII probe data could eliminate the need for some monitoring equipment such as loop detectors.

Overall, estimated mobility benefits range from $0.7 billion to $1.3 billion in present-value, depending on whether the 5 percent or 10 percent improvement in travel times is assumed. In either case, incremental costs are assumed to be close to zero, so estimated net benefits in the range of $0.7 billion to $1.3 billion. In the summary table below, a midrange estimate of $1.1 billion is used as the base case, reflecting an assumed travel time improvement of 8 percent.

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[17] 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.

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. The Texas Transportation Institute's 2005 Urban Mobility Study estimates that signal timing adjustment produces an annual reduction in travel delays equal to 10.9 million hours across the nation's 75 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.[18] Taking a midrange value of 12 percent improvement, the incremental benefit of VII at full deployment is therefore approximately 1.3 million hours of delay reduction per year.

As with ramp metering, calculations of future-year benefits have not been adjusted for differing levels of OBE penetration, based on the assumed sufficiency of a relatively small number of probe vehicles.[19] Adjustment has, however, been made to account for future growth in VMT, since additional vehicle traffic translates into additional potential for delay reductions, with an assumed VMT growth rate of 0.8 percent per year.

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, these costs would be incurred irrespective of VII. At the same time, achieving the benefits of the application may require some additional staff time and expenses to update the timing on signals that have not yet been incorporated into timing plans. ITE estimates that there are approximately 30,000 signals nationwide that are in need of timing plan optimization

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[18] 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.

[19] An adjustment may however be needed to account for the phase-in of RSE, depending on the assumptions about the traffic analysis. These calculations assume that it is not strictly necessary to have a roadside unit at a particular intersection in order to re-optimize that intersection's signal, only a relatively well-dispersed network of RSE to capture traffic data in that area. If, instead, it is necessary, then benefits would need to be re-calculated accordingly.

at a rough average cost of $350 each. Thus, this application *may* have a one-time cost of approximately $10 million, and this cost figure (discounted appropriately) is included in this analysis in order to be conservative.

Applying the standard values of travel time savings, discounting future benefits into present values, and summing across the project time horizon yields total benefits in the range of $108 million to $203 million, depending on whether the lower or higher estimate of travel time savings is used. A midrange estimate of 12 percent improvement yields benefits of $162 million; this is the figure listed in the summary table below as the base case. Costs equal $7.5 million in present-value. Net benefits thus range from approximately $100 million to $195 million, with a midrange estimate of $155 million.

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. Travelers would see somewhat better and safer road conditions.

Analysis of this application is based in part on the idea that 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.

There are two main approaches to estimating the benefits of the application. The first is to count the benefits to motorists – in terms of safety, time savings, fuel savings, etc. – that will accrue if VII enables transportation departments to clear the roads of snow and ice more quickly and effectively (while using the same resources). This is analogous to the approach taken in research[20] that estimated the overall benefit-cost ratio of existing winter maintenance activities at 6.5:1, or about 2.4:1 for automated de-icing of specific roadway segments.[21] Determining the actual impacts of winter maintenance and how this translates into vehicle speeds and crash reductions, however, can be quite challenging. One research report that attempted to do so found that RWIS systems, on their own,

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[20] Hanabali, R. "The economic impact of winter road maintenance on road uses," Transportation Research Record, No. 1442, Transportation Research Board, Washington, D.C.

[21] Stowe, R. "A benefit-cost analysis of intelligent transportation system applications for winter maintenance," Transportation Research Board, 80th Annual Meeting, 2001.

generally do not generate sufficient benefits (again in terms of safety, time savings, and operating cost savings) to justify their high costs.[22]

The other approach, which is used in this BCA, is to assume instead that VII will allow highway departments to achieve the same level of snow/ice clearance as today, but at a lower cost in terms of labor and materials. In this case, the "benefits" of the application are not the benefits to individual motorists but rather the cost savings realized by highway departments.

The concepts underlying this approach are outlined in a research paper[23] that describes the benefits of using advanced technologies – in particular, accurate, 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. Because the exact road surface temperature is usually unknown, and because the consequences of under-salting are generally greater than those of over-salting, 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. The report does note, however, that because forecasts are fallible, using this approach can also send costs higher; the authors calculate that Iowa DOT spent an additional $15,000 in labor and materials during the 1996-97 winter season due to a "forecast buster" storm. The paper includes some estimated average costs of labor and materials for winter maintenance that could be used in benefit estimation, though they may need to be updated and adjusted for regional differences.

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 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,

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[22] Boselly, S.E., III. "Benefit-cost assessment of the utility of road weather information systems for snow and ice control," Transportation Research Record, No. 1352, Transportation Research Board, 1992.

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

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 advantage of the probe vehicle data is that it can fill gaps in sensor coverage. The disadvantage is that it is by nature an indirect measurement. As the write-up for a related use case notes, "There is significant research that will be required to understand how to remove vehicle biases leaving representative data sets that accurately describe the road weather and surface environment. There will also need to be research in deciding how best to combine complementary weather data with the VII-collected data to add quantitative value to the information."

In essence, 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.

Again, for simplicity (and in the absence of additional data), this BCA captures the impacts of the Winter Maintenance application not as benefits to motorists but as reductions in operating costs for state and local highway departments. 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.[24] 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.[25] Based on this 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. Summed up across the VII project time horizon and discounted back into present value, this equals roughly $400 million in cost savings. This figure is listed as a negative value in the "cost" column in the summary table in Section V, since it is more naturally thought of as a cost savings rather than a mobility benefit.

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

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

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 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 are largely safety-oriented. 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 benefits of these applications would primarily come from a reduction in crashes caused by unexpected changes in conditions, poor weather, and other similar factors.

A secondary set of benefits would be the mobility benefits – principally time savings – that 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.

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. A review of the ITS 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[26] 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. The literature also has some information on the potential safety benefits of improved traveler information. In future iterations of BCA for the VII program, these may form the basis of a consolidated benefits estimate for this group of four applications. At this time, however, these applications have not been defined in sufficient detail to permit an estimate of benefits or costs, and thus their estimation has been deferred.

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.

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[26] 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.

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[27] 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,[28] 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 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.

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.

Toll payment will 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

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

[28] 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.

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.

Probe-Based Mapping

This application's concept is that electronic map data would be supplemented and updated with location-based information from vehicle OBE – e.g. stop sign locations and lane information. This would provide the lane- and location-specific information needed to support other safety and mobility applications, such as EBL, signal violation warnings, and in-vehicle navigation map updates.

As this description suggests, this is largely a supporting application in that it enables and enhances some of the other Day One applications described in this report. At the VII Working Group meeting in February 2006, there was general agreement with the BCA team's characterization of this application as a supporting one, and with the proposed approach of not calculating a separate set of costs and benefits for probe-based mapping itself. It has also been suggested, however, that probe-based mapping may provide cost reductions for either VII or commercial services. The possibility of quantifying these cost savings will be explored as part of future VII BCA efforts.

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 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 yet to be developed or shared with the BCA team, and quantification of their benefits is not currently possible.

V. 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 III presents an estimate of the overall life-cycle costs of VII, based on current assumptions about deployment schedules and equipment. In Section IV, each of the proposed Day One 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 I, 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 2006. In keeping with conventional BCA practice, all dollar values are in real terms, in this case 2006 prices.

As Table 4 shows, these calculations indicate that the VII initiative, with the currently envisioned set of applications, would generate net benefits of approximately $29 billion. The benefit-cost ratio is 2.8 to 1.

These calculations of benefits are "conservative" in the sense that they do not yet include the potential contributions of several Day One applications, or indeed the many potentially useful applications that may be launched well after Day One. This phase of the BCA also does not include the environmental benefits – reductions in harmful vehicle emissions – that would be expected to stem from several applications' reductions in travel times and crash-related congestion.

Table 4. Summary of Estimated VII Benefits and Costs
(Present Values, Millions of 2006 Dollars)

Program Elements	Present Value of Benefits	Present Value of Costs	Net Benefits
Signal Violation	12,903	154	12,749
Stop Sign Violation	7,349	154	7,195
Ramp Metering	1,063	0	1,063
Traffic Signal Timing	162	7	155
Curve Speed Warning	6,908	154	6,754
Electronic Brake Lights	17,363	154	17,209
Winter Maintenance	0	- 407	- 407
Other Applications	TBD	TBD	TBD
VII Infrastructure, Operations, and Maintenance	N/A	16,110	- 16,110
TOTAL	$45,747	$16,325	**$29,422**

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 5 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 last two rows of the table, which test the influence of "application benefit ranges," refer to applications for which a low and high estimate of benefits was specified in Section IV. The other cases refer to changes in economic variables or other assumptions.

The next steps for this analysis will consist of iterative rounds of updates to the benefit and cost figures based on input from the VII program and Working Group, along with revisions related to new applications or revised use-case definitions.

Table 5. Summary of Initial BCA Sensitivity Testing

	Present Values in Billions of 2006 Dollars			**B/C Ratio**
	Benefits	**Costs**	**Net Benefits**	
VII BCA Base Case (All Values as in Report Text)	45.7	16.3	29.4	**2.8**
Sensitivity Case Tested:				
Discount Rate of 3%	113.9	33.6	80.3	**3.4**
2x Higher OBE Costs ($100/unit for installation plus $2/unit/year for O&M)	45.7	27.8	18.0	**1.6**
25-Year Project Horizon	34.5	13.9	20.7	**2.5**
Using Low End of Application Benefit Ranges	45.3	16.3	29.0	**2.8**
Using High End of Application Benefit Ranges	56.1	16.3	39.7	**3.4**