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*Desk Reference and Tools for Estimating the Local, Regional, and State-Wide Economic Development Benefits of Connected Vehicle to Infrastructure Deployments*

**Desk Reference**

**for Estimating the Local, Regional, and State-Wide Economic Development Benefits of Connected Vehicle to Infrastructure Deployments**

***Final***

Submitted To

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# Introduction

## Project Background and Purpose

Connected vehicle (CV) technologies and applications have developed significantly over the last 20 years and have been demonstrated in test beds of increasing size and complexity. Significant efforts have been expended over the last ten years to identify, develop and demonstrate new technologies in the pursuit of a connected vehicle environment in which vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications enable greatly increased safety, mobility and environmental benefits for surface transportation. The consensus of research in the area is that deployment of CV communications technology (e.g., cellular, Wi-Fi and Dedicated Short Range Communications (DSRC)), applications, and supporting services have the potential to significantly improve operations of nation’s surface transportation systems. A fully deployed CV environment has the potential to improve safety, increase mobility, reduce environmental impacts, and reduce the agency costs of operations. These likely benefits have prompted the National Highway Traffic Safety Administration (NHTSA) to consider rulemaking that would require the deployment of DSRC devices in light vehicles and the U.S. Department of Transportation (USDOT) to plan to award grants in 2015 for CV deployment to state and local agencies in its CV Pilot Deployment Program.

However, the success of strategic policies regarding CV technologies at the federal level is partially dependent on investment decisions by other stakeholders. While Federal regulations and mandates can direct the adoption of CV technology in vehicles, the roadway infrastructure needed for a mature CV environment must be put in place by the state, local and regional entities charged with construction, maintenance and management of the roadway systems.

These agencies operate in a constrained and competitive fiscal environment. Expenditures for construction, rehabilitation, maintenance and operations of the transportation infrastructure have to be justified against alternative uses of scarce funds. Reaching the full potential of CV envisioned by national policy-makers requires significant investments by states, counties and Metropolitan Planning Organizations (MPOs) – investments that are unlikely to be made unless these public entities understand their local and regional economic impacts.

Transportation policy makers have been advocating for the use of economic analysis tools to better inform transportation planning and investment decisions for some time. Several commonly recommended methodologies, including benefit-cost analysis and economic impact analysis, among others, are available to state and local transportation departments to facilitate making these decisions, including some studies which have refined these approaches for specific types of roadway investments.

## Connected Vehicle Desk Reference

The Office of Transportation Policy Studies (HPTS) at the United States Department of Transportation’s (USDOT) FHWA and the USDOT Intelligent Transportation Systems Joint Program Office (ITS JPO) have joined to contract with Battelle (with HDR and Synesis) to develop a Desk Reference and Tools for Estimating the Local, Regional, and State-Wide Economic Development Benefits of Connected Vehicle to Infrastructure Deployments. The purpose of the desk reference and tools is to assist state and local transportation agencies and MPOs to perform economic analyses, including benefit-cost analyses and estimation of potential economic development impacts, of vehicle to infrastructure (V2I) technology and application deployment for their programs, projects, and regions.

This desk reference and accompanying tool provides a framework for ongoing analyses. While costs and benefits associated with V2I technologies and applications presented in this desk reference and the accompanying tool have been drawn from other existing studies, both the desk reference and tool have been structured so as to enable analyses to incorporate new data on costs, direct and indirect impacts, and other factors as deployments expand and new information becomes available.

## How to Use the Desk Reference and Tool

This desk reference has been created for ease of use across a wide range of experience and exposure to V2I. This document can support use of the accompanying tool or separate efforts to measure the impact of public investments in V2I infrastructure for users new to economic analysis as well as experts in transportation benefit-cost analyses (BCA).

This desk reference begins with a general overview of economic analysis and some of the approaches used to measure economic impact, all in **Chapter I**. These sections provide a thorough look at literature that has been written on the topic. It also examines V2I technology implementation strategies and how the technologies are currently being used. The following outlines the remaining chapters:

**Chapter II**, Overview of Economic Analysis Approaches for Operations, presents a thorough review of the current tools and methods available for measuring economic impact. Some of the approaches covered include BCA and economic impact analysis (EIA). Methods used for more specific needs such as gravity models and real estate market analysis are also covered in this chapter.

**Chapter III**, Connected Vehicles, V2I Applications, Deployment Scenarios, and Their Impacts (Agency, User, and Societal Benefits), sets the stage for the impacts being analyzed by the methods described in the previous chapter. Looking into the current V2I technology landscape, this chapter describes what concepts, applications and deployment methods are presently in use. Findings in the literature with regards to the impacts and benefits of V2I implementation as well as key data are presented.

**Chapter IV,** V2I Benefits Estimation Tool (VBET), provides a basic guide to the tool, and discusses how it works together with other tools developed under the auspices of FHWA to support state, local and regional decision makers plan for V2I investments.

**Chapter V**, Conducting Economic Analysis for V2I Applications, builds upon the previous chapter, providing guidance on how to tailor analysis methods specifically to V2I deployments. Guidance on how to qualitatively assess impacts of the technologies is presented, including discussions on benefits and impacts that may not be either quantified or monetized confidently, together with direction on how this information can be used to further enhance and inform decision making.

**Chapter VI**, Upcoming and Expected Research and Studies, shifts from the present conditions surrounding V2I technology to the future outlook of those technologies. The chapter provides a brief overview of ongoing efforts in the field including research by AASHTO and the USDOT-funded state pilot programs. These efforts made in the research of V2I technologies help set the stage for future investment and deployment.

The desk reference closes with a **Glossary** including common abbreviations that provides the definitions and information needed to gain an understanding of the material being presented within this desk reference. Basic terminology and concepts that will appear throughout this document have been captured and explained in this chapter.

The chapters of this desk reference have color coded sidebars to facilitate quick navigation. The following table shows the chapter order and color representation.

Table 1: Chapter Layout

|  |  |  |
| --- | --- | --- |
| **Chapter** | **Title** | **Color** |
| 1 | Introduction |  |
| 2 | Overview of Economic Analysis Approaches for Operations |  |
| 3 | Connected Vehicles, V2I Applications, Deployment Scenarios, and Their Impacts (Agency, User, and Societal Benefits) |  |
| 4 | Existing Tools and Guides |  |
| 5 | Conducting Economic Analysis for V2I Applications |  |
| 6 | Upcoming and Expected Research and Studies |  |
| 7 | Appendices |  |
| 8 | Glossary; Bibliography |  |

In addition, a tool for estimating the local, regional, and state-wide economic impacts benefits of connected vehicle to infrastructure deployments was developed to accompany this desk reference. It is described in further detail in a section on the V2I Benefits Estimation Tool (see page 49).

### Where to Find Information

***Common Questions and Where to Locate More Information***

***Where do I go for:***

* ***Help in Understanding Benefit-Cost Analysis (BCA)?***
* *See the section on “Benefit Cost Analysis (BCA),” beginning on page 16 in Chapter II*
* ***Information on Estimating Economic Development Benefits?***
* *See the section on “Overview of Economic Development,” beginning on page 12 and the section “Appendix: Other Approaches to Modeling Economic Development,” beginning on page 84, both in Chapter III*
* ***Working with the Accompanying V2I Benefit Estimation Tool?***
* *See Chapter IV “V2I Benefits Estimation Tool,” beginning on page 49*
* ***Information on the Research Conducted to date on V2I Impacts?***
* *See Chapter III “Connected Vehicles, V2I Applications, Deployment Scenarios, and Their Impacts (Agency, User, and Societal Benefits)” beginning on page 23*

The desk reference is designed to include information ranging from a basic introduction to the world of economic analysis and V2I technology to specific approaches and methods needed to carry out a rigorous analysis of a specialized V2I scenario. The following breakdown will provide a high level look at where to locate information needed by the user of this guide.

* What is economic analysis and how is it used?
  + A discussion regarding the definition of economic analysis can be found in Chapter 1.
  + Information regarding the types and use of economic analysis can be found in Chapter 3.
* What impacts are involved with V2I technologies and how do I measure them?
  + Information regarding the potential impacts associated with the implementation of V2I technologies can be found within Chapter 4 of this desk reference.
  + The processes used to measure the impact of V2I technologies and associated applications are located in Chapter 3.
* What deployment strategies have been implemented and how have they fared?
  + Information regarding implementation of V2I technologies can be found in Chapter 4.
  + The resulting impact of these deployments is also located in Chapter 4.
* What approach and strategy should I use for implementing V2I technology?
  + Instruction on the decision making process and how to proceed with the implementation of V2I technology is found in Chapter 6.
  + The analysis tool developed in tandem with this desk reference is another valuable resource to help guide you through the implementation process. More information in this tool is provided below.

This desk reference is designed to work in partnership with a separate Excel-based tool, ***V2I Benefit Estimation Tool***, which was developed to help guide State and Local agencies as they face decisions on the implementation of infrastructure necessary for V2I applications. The tool has four main capabilities to help users:

1. Investigate the potential impacts of V2I applications they are considering for implementation.
2. Identify the appropriate economic methods or tools needed for a specific situation.
3. Conduct an economic analysis of V2I applications.
4. Access to more information regarding the tool and desk reference, including user support and additional documentation.

## What is Economic Analysis?

FHWA’s *Economic Analysis Primer* introduces “economic analysis” as a methodology that “allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe” and “describes actual applications of economic analysis methodology, especially life-cycle cost analysis and benefit-cost analysis” (page 7). The Primer discusses Benefit-Costs Analysis, Life-cycle Costs Analysis, and Economic Impact Analysis. Other documents take an even broader approach, without any specific definition. Yet, all of these refer to changes to the economy or economic activity due to the addition of a transportation investment.

Economic analysis, particularly benefit-cost analysis, is viewed as a key component of evaluating potential projects. The use of economic analysis can impact all levels of the decision making process, from planning and design to construction. It can provide a wealth of information to decision makers by comparing the costs of a project with its benefits and measuring the impacts the project can have on the user, local area and society as a whole. Economic analysis also provides decision makers with the means to compare projects against competing projects. Using standard measures across projects allows agencies to determine which projects give the greatest return to the public good. Due to the limited amount of transportation funding available, it is important that the most beneficial projects are selected for funding.

## Why Use Economic Analysis for V2I Technologies?

The focus of V2I research and demonstration to date has been on developing technology and applications. While there is significant consensus that the apparent benefits of V2I deployment are real, it is less clear how substantial those benefits are, when and how fast they accrue, and which stakeholders might receive particular benefits.

In an era of limited transportation funding, every investment dollar is precious to state, regional, and local agencies and case must be made for the value of each investment. Thus, State, local, and regional agencies need more information about the potential benefits of V2I infrastructure investments as a means of justifying V2I deployment plans, especially when funding those plans might necessitate program reductions in other areas.

Assessments of potential V2I benefits and costs to date have not satisfied the agencies’ need for budgetary justification. To date, assessments of impacts have been largely qualitative and there is a need for broader applicability. The understanding of how benefits and costs are realized as deployments are deepened and expanded over time, is still forming and depends on policy decisions not yet formalized. As these technologies continue to evolve quickly and depend to some extent on local and regional public investments to fully capture their potential, the public investment decisions for supporting these technologies are crucial. This desk reference and accompanying tool allowing for more detailed analysis of the economic benefits and costs of V2I deployment at the state, local, and regional levels to assist in policy and deployment decisions

## What Makes Connected Vehicles Different from Other ITS Investments, and the Implications for Estimating Benefits?

The deployment of applications and infrastructure in the entire CV environment, including V2I, is fundamentally different than in traditional intelligent transportation system (ITS) settings – CV technology automates actions within the car whereas other ITS improvements have automated actions in the environment. CV applications are also cooperative, requiring direct interaction between two vehicles (i.e., vehicle-to-vehicle, V2V, applications) or between a vehicle and roadside infrastructure (i.e., V2I applications) to be effective. As such, the costs and benefits of deployment are spread among travelers and deploying agencies. No single party controls the timeframe and locations where applications become effective.

As of this writing, CV, and thus V2I, technology is still in early stages of development and has not yet been deployed on a large scale. Due to the collaborative nature of CV technology (i.e., vehicles working with infrastructure and with other vehicles), the technology must be implemented across many platforms in order to have an impact. The benefits of CV investments are not realized until a critical mass of CV-equipped vehicles is in operation and the necessary infrastructure is in place. Therefore, long lag times are possible or even likely between the time of initial investments by state and local entities and the point at which notable benefits begin to accrue.

Assessments of the economic impacts of CV applications must incorporate some estimate of the rate of adoption of CV technology in the entire fleets under study. If they ignore technology adoption rates and implicitly assume CV technology is adopted immediately, assessments will significantly over-estimate benefits.

In addition, many components and applications can be deployed together in ways that may create efficiencies (or inefficiencies) for secondary costs such as network security infrastructure and operations monitoring. Again, since these are still emerging technologies, there are no observed efficiencies/inefficiencies upon which to base assessments of future deployments. Planners and decision-makers must grapple with the limited information available on what may be significant factors in aggregate costs and benefits in the long-run.

## Contacting FHWA for Further Information on CV

Multiple offices within U.S. Department of Transportation are supporting efforts on connected vehicles and can be valuable resources for state, local, and regional planners and transportation officials seeking additional information. For further information, contact:

* US Department of Transportation’s Intelligent Transportation Systems Joint Program Office.

<http://www.its.dot.gov/>

Individual staff members are listed by topic at: <http://www.its.dot.gov/stafflisting_subject.htm>.

Listing by topic: <http://www.its.dot.gov/its_fhwa_resources.htm>

# Overview of Economic Analysis Approaches for Operations

Economic analysis can be a useful tool in the decision-making process when planners are faced with multiple investment demands, but limited resources. It provides decision makers with an approach to evaluating and comparing projects against each other according to their projected economic benefits. These analyses can produce estimates of the scope and size of total net benefits, the relative size of benefits per dollar expended, benefits by beneficiary group (the private sector, such as trucking and other transport firms, etc. versus public agencies, such as EMS departments, local transit agencies, etc.), and the timing of benefits of individual projects and alternative implementations (i.e., some applications may experience significant ramp up of benefits faster than others). The estimates can help transportation decision makers in selecting the most desirable alternatives among several, determining the optimal timing of an investment/deployment, picking between multiple types of infrastructure investments, and facilitating public understanding of complex projects. As V2I and other CV technologies moves from infancy to a more mature state of development, economic analysis can be used to better understand the impact V2I and other CV technologies would have on travelers and society as a whole, thus improving its overall deployment.

**Summary**

* There is an important distinction between direct and indirect impacts. Direct impacts, such as travel time, vehicle operating costs, emissions, and noise, flow into indirect impacts, such as changes in economic activity.
* Beneficiaries of a V2I deployment can include:
  + Users (of the technology and the facility on which it is deployed);
  + Local agencies;
  + Non-users;
  + The community as a whole.
* There are differences in methodology for benefit-cost analysis (BCA), economic impact analysis (EIA), and the estimation of economic development changes due to transportation.

USDOT, TRB, AASHTO, and GAO have published reports or guides which explicitly address approaches and methods for assessing the economic effects of transportation infrastructure. Table 2, below, lists documents which were heavily referenced during the preparation of this desk reference. This list of key federal and national reports on economic assessments for transportation is by no means exhaustive and certainly other guidance can be found on this topic. All of these documents discussed the usefulness of economic analysis (which is termed “engineering economics” in NCHRP Synthesis 424 and engineering economic analysis in NCHRP) in transportation decision-making. A further discussion of definitions for these economic analysis approaches is found later in this section.

Table 2: Federal and National Reports on Assessing Economic Assessment of Transportation Projects

| Title | Year | Economic Analysis Approach Discussed in Document | | |
| --- | --- | --- | --- | --- |
| Benefit-Cost Analysis (BCA) | Economic Impact Analysis (EIA) | Economic Development |
| GAO, *The Benefits and Costs of Highway and Transit Investments*, GAO-05-423SP | 2005 | x |  |  |
| GAO, Highway and Transit Investments: Options for Improving Information on Project’s Benefits and Costs and Increasing Accountability for Results, GAO-05-172 | 2005 | x | x |  |
| FHWA, *Economic Analysis Primer* | 2003 | x | x |  |
| FHWA, *FHWA Highway Economic Requirements System (HERS): Technical Report* | 2005 | x |  |  |
| NCHRP Report 786 *Assessing Productivity Impacts of Transportation Investments* | 2014 | x | x |  |
| NCHRP 466: *Desk Reference for Estimating the Indirect Effects of Proposed Transportation Projects* | 2012 | x |  | x |
| NCHRP, *Guidebook for Assessing the Social and Economic Effects of Transportation Projects*, NCHRP Report 456 | 2001 | x |  | x |
| NCHRP, *Improved Methods For Assessing Social, Cultural, And Economic Effects Of Transportation Projects*, NCHRP Project 08-36-66 | 2008 | x |  | x |
| NCHRP, *Monetary Valuation of Hard-to-Quantify Transportation Impacts: Valuing Environmental, Health/Safety & Economic Development Impacts*, NCHRP 8-36-61 | 2007 | x |  | x |
| NCHRP, *Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners,* Project 8-36 Task 101 | 2011 | x | x |  |
| NCHRP SYNTHESIS 424; *Engineering Economic Analysis Practices for Highway Investment A Synthesis of Highway Practice*. | 2012 | x | x | x |
| USDOT, TIGER BCA Guidance | 2014 | x |  |  |

All of the reviewed documents suggest using BCA as a method to assess the relative value of a transportation investment or to assist in choosing between multiple alternative options. BCA measures the direct user benefits of a transportation project. There is general consensus on this approach and terminology.

Additionally, many documents suggest using EIA to assess economic impacts. In some cases, the less defined term “economic development” is used as surrogate for EIA methodologies. That is, there does not appear to be a standard, consistent methodology associated with “economic development” in the reviewed literature except for those studies that overlap with EIA methods. Still, there is a set of metrics that were identified in relation to EIA that are consistently used in measuring economic impacts (e.g., employment, business sales, personal income, and gross regional product). Often, these measures are also used to measure economic development impacts although some planners also look at issues such as land-use changes, accessibility, and business attraction. These last two effects can also be included as part of BCA or EIA.

Few guidelines and methodologies for estimating economic development impacts for state and local practitioners were found in the recent general guides reviewed, so a further review of other modeling approaches was conducted. This additional review found that many of these tools require coordination or use within other models, some of which must be customized. Many are currently not very accessible to state and local transportation decision makers, due to cost, the need for relatively experience technical users, customization requirements, and other factors. This makes it difficult to adapt them into a tool which can be used by a range of state, local and regional decision makers.

All three of these methodologies are discussed further, after the following short discussions on direct/indirect effects and groups of beneficiaries.

## Direct Versus Indirect Effects

Transportation projects can have a direct impact on individuals and the economy as well as indirect impacts which arise out of those direct impacts. Direct impacts can be described as changes or impacts to users or local or regional area most directly from the use of the transportation facility, such as changes in travel time, vehicle operating costs, emissions, noise, etc. Indirect impacts include those changes in economic activity in the area (local or regional) that arise due to the direct impacts. “Lowering transportation costs for users and improving access to goods and services enables new and increased economic and social activity.” (GAO-05-172, page 14). The distinction between direct and indirect impacts effects is important and nearly every document reviewed at least touches on the distinction. Most of these reviewed reports group the impacts of transportation into direct, or first order, and indirect, or second order, impacts.[[1]](#footnote-1)

It is important to remember that in this approach, indirect impact flow from direct impacts and thus should not be added together, for several reasons including the fact that: a) they “may also represent capitalization of the direct user and social benefits” (GAO-05-172, page 14) and b) they may include activity which is transferred from one part of the community to the other (addressed as a transfer of economic activity from one area to the other in several of these documents, including the *Economic Analysis Primer*, *TIGER Guidance*, and GAO -05-172).

Another critical distinction raised by these reports is that between short-term impacts – from the building the transportation facility – and the long-term impacts that derive from its use. The economic development impacts of transportation projects are typically grouped within two broad categories:

* Impacts associated with spending on construction (including planning, design, and engineering) and/or changes in operations and maintenance expenditures; and
* Impacts resulting from improvements in the performance of a transportation system.

Not all of the reviewed reports on economic assessments for transportation discuss this in detail, but several note the fact that there are potential benefits in both categories and that these require separate analyses (see NCHRP 456, page 110). Connected vehicle technology is still early in its development and but may have the potential to impact local or regional economies if it can boost local or regional productivity or increase the attractiveness of the communities for business location.

## Beneficiaries and Types of Benefits

The dozen reports in Table 2 categorize impacts/benefits in slightly different, but related, groups. All the reports acknowledge that there are many potential direct impacts that affect just the users of the transportation facility and that other impacts can affect the community as a whole (such as changes to emissions). In addition, several discuss agency impacts in terms of changes in operations and maintenance costs and a few distinguish impacts which affect users of other transportation facilities (as when drivers divert from that road to another or use transit, as noted in NCHRP 8-36-101).

Most of these reports categorize the accrued benefits of a new transportation project to one of three groups:

* The users of the facility;
* Non-users (individuals);
* The community as a whole.

Non-user benefits include those to people not directly using the new transportation project, but still benefiting, such as drivers on neighboring roads which have become less congested. Community benefits include those which can be experienced by everyone irrespective of whether or not they use the facility, such as reductions in noise and emissions, improved livability, and property values.

NCHRP 8-36-101 adds a fourth category to the three noted above, termed “other” and which includes benefits such as agglomeration impacts (economies of scale that would arise from improved mobility or concentration of economic activity), additional land premiums, and option values (page 12-16). If community benefits are expanded to include the economy as a whole, then this category can cover those in NCHRP 8-36-101, which are likely to be quantifiable by state and local agencies.

These categories reflect the fact that most transportation investments are undertaken to improve mobility. Yet, V2I and other CV applications will also generate significant savings for agencies, mostly in reductions in future outlays for maintenance, emergency response, etc. These agencies benefits can be thought of as a separate category, or as under one of the others above, as dictated by the situation.

User benefits discussed in these reports generally include travel-time savings, reductions in crashes, and reductions in vehicle operating costs (for example see GAO, page 12; NCHRP 8-36-101, page 4-1; *Economic Analysis Primer*, p 17). Non-user benefits are not mentioned as frequently, but when discussed they included reductions in air pollution and noise as well as travel-time savings, reduction in congestion, and fewer crashes on other roads as users change their routes to travel on new or improved roads instead of other neighboring ones. Community benefits were frequently discussed and generally included environmental and livability impacts, and sometimes included measures such as improved property values, land use premiums and other impacts on the land or economic activity in the area.

Meanwhile, costs fall into one of two categories – the agency investment costs (to build and manage the project) and any potential users costs sometimes termed ‘disbenefits’. These disbenefits can include temporary increases in travel-time, noise and other inconveniences arising from the project’s construction period, as well as potential long-term impacts such as increases in noise and/or emissions arising from additional (induced) travel on the new roadway or the now less congestion neighboring facilities.

## Overview of Economic Development

On FHWA’s webpage for Economic Development, the agency acknowledges that “[t]he term "economic development" has no specific definition in the Federal-aid highway program.” (see <http://www.fhwa.dot.gov/planning/economic_development/>). However, the website presents a working description of the term: “**Economic development refers to the policies and actions that promote economic goals within a specific geographic area**.”[[2]](#footnote-2)

The comparative lack of a definitive definition of economic development for transportation projects in FHWA is mirrored in the broader literature on assessing economic impacts reviewed for the development of this desk reference and the V2I Benefits Estimation Tool (VBET). There does not seem to be a standard definition of “economic development” or economic impacts among these documents, as the measures and impacts being discussed are often quite different and sometimes overlap with what is often assessed under a standard ‘economic impact analysis,’ or EIA.

Specifically, four of the guides reviewed use the term “economic development” in discussions of impacts of transportation projects: NCHRP 424; NCHRP 456; NCHRP 466; and NCHRP 8-36-61. But only two of these documents contain definitions of economic development:

* NCHRP 456 includes an entire chapter titled “Economic Development” in which it is defined as “. . . the process through which economic activity in an area is expanded to provide more jobs and income to the area’s residents.” (page 107; also see glossary on page 234).
* NCHRP 8-36-61 states that “economic development commonly refers to changes in business activity that expand (and improve the nature of) jobs and income for residents of an area.” (page 30)

One consistent element in the use of the term economic development is that it always refers to indirect impacts. But its use can refer to either land use changes, growth in jobs, income, and/or economic activity. In addition, there is no uniform approach to estimating economic development given in these documents (only NCHRP 456 and NCHRP 8-36-61 provide any specific guidance) and both provide combinations of methods of estimating the changes in regional spending such as market analyses, case studies and use of models.

This relative lack of clarity regarding the terminology of economic development and economic impact stands in stark contrast to the consistent terminology and descriptions used in discussions regarding analyses of economic impacts in the transportation economics literature. Therefore, care was taken to delineate them in this document.

### Impacts Associated with Economic Development

Just as there is variety in the definition of economic development, there are differences in its estimation. While there may be a need for more clarity on economic development, economic impact, and the differences, certain key themes were found in the reviewed key federal and national reports on economic assessments for transportation which sought to address economic development which are relevant for a V2I desk reference and tools.

Several of key federal and national reports on economic assessments for transportation discussing economic development note how attractive economic development metrics are to local and regional policymakers. In fact, NCHRP 08-36-66 states that the majority of transportation projects are driven by economic development factors. The report explicitly raises the concern that this focus may lead to decisions being made by transportation agencies that are not fully aligned with the stated community goals in transportation plans and vision statements.[[3]](#footnote-3) NCHRP 08-36-66 also notes, though, that many agencies have identified this potential problem and have set goals or processes to ensure that community factors and stated goals are integrated into the decision making process. NCHRP 08-36-61 also notes that economic development can be one of the leading factors, if not the primary reason, for transportation investments, and NCHRP 466 acknowledges that economic development is often used as a means of justifying a project’s importance.

***Where do I find details on tools and methods for estimating economic development benefits for my project?***

* *Go to subsection “Appendix: Other Approaches to Modeling* Economic Development*” starting on page 84.*

This finding is further supported by the results of a survey of state agencies conducted for *NCHRP Synthesis 424: Engineering Economic Analysis Practices for Highway Investment*. Two thirds of the states surveyed in NCHRP Synthesis 463 mentioned conducting evaluations of likely economic development impacts at least occasionally with a smaller portion saying they were routinely used.

The reports all support a conclusion in the white paper, *Economic Benefits of Connected Vehicle Technologies*, included as Appendix A in the approved scope of work that:

*Economic development impacts tend to be very important to State and local decision-makers, and can have real effects on communities’ economic vitality and quality of life. However, they do not capture the net benefits to society.*(page 23).

A few of the reviewed reports offer guidance on estimating economic development impacts. The steps laid out in NCHRP Report 456 in its chapter on economic development are:

* Measure the transportation factors affecting economic development;
* Estimate the direct effect on business competitiveness;
* Estimate the direct effect on business growth or decline;
* Estimate indirect, induced, and dynamic effects on economic development.

Suggested methods to use include:

* Expert interviews;
* Market studies;
* Case studies;
* Computer models;
* Input-output models.

Additional methods include location quotients and cluster analysis, along with shift-share and comprehensive economic development strategies (CEDS).

***Where do I find for help on preparing a BCA on my project?***

* *See FHWA’s Economic Analysis Primer, 2003; FHWA’s Operations Benefit/Cost Analysis desk reference [*[*http://www.ops.fhwa.dot.gov/publications/fhwahop13004/fhwahop13004.pdf*](http://www.ops.fhwa.dot.gov/publications/fhwahop13004/fhwahop13004.pdf)*]; or NCHRP’s Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners [*[*http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)\_FR.pdf*](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)_FR.pdf)*].*
* *See Chapter IV ”V2I Benefits Estimation Tool” starting on page 49.*
* *Use the V2I Benefits Estimation tool for estimating the local, regional, and state-wide economic development benefits of connected vehicle to infrastructure deployments developed with the desk reference.*
* *Use BCA.net, FHWA's Web-Based Benefit-Cost Tool for Highway Projects [*[*http://bca.transportationeconomics.org/models/bca-net*](http://bca.transportationeconomics.org/models/bca-net)*].*

NCHRP Synthesis 424 discusses how economic development benefits can be estimated according to National Economic Development (NED) guidance. Data for these estimates were obtained from such public sources as the US Census Bureau, the Congressional Budget Office and the Minnesota Department of Employment and Economic Development (via its IMPLAN model). This document warns several times about incorrect treatment of economic development impacts as project benefits in transportation projects as they can lead to double-counting the benefits already considered in another form.

Although TCRP Report 35 focuses on transit, its discussion of employment and income growth impacts can be informative for other modes. The report describes how transportation projects can shift employment opportunities to transit corridors. This redistribution of employment can lead to income growth in that particular area but can also reduce employment and income in another area. When collecting primary data, good sources include transit agency officials, economic development agencies, business groups, elected officials and developers. For this reason interviewing businesses, economic development professionals and representatives of areas affected by the project is identified as a key part of the analysis process.

## Benefit Cost Analysis (BCA)

### What is it?

BCA is a well-established methodology to help decision makers weighs the costs of the decision against the social welfare gains from the decision. It provides a well-defined approach for estimating the likely costs and benefits of a transportation investment that incorporates the timing of changes over a project’s “life-cycle” and monetizing (i.e., putting a dollar value on) them. BCA is a common framework in transportation economics such that all TIGER grant applications have been required to include BCAs in their application.

### What is Measured in BCA?

A critical part of the BCA approach is that it measures the direct benefits and costs of a project. FHWA’s *Economic Analysis* *Primer* summarizes this as:

*Direct benefits and costs are the first order or immediate impacts of the transportation project on users and nonusers, and consist of elements described earlier in this primer, including changes in travel time, crashes, vehicle operating costs, agency construction costs, and pollution costs. BCA typically does not measure how these direct benefits and costs are converted into indirect effects on the economy, such as changes in employment, wages, business sales, or land use.* (page 32)

According to FHWA’s *Economic Analysis* *Primer*, the main appeal of BCA is that it considers all benefits and costs borne by society regardless of the party who receives them and the form these costs and benefits take, thus providing a true assessment of the “net benefits” (i.e., benefits above costs) to society. The *Economic Analysis* *Primer* focuses on BCA (with a shorter discussion on EIA), stating that “benefit-cost analysis is the most comprehensive method to evaluate the reasonableness of highway projects in economic terms” (page 35).

Standard BCA relies on monetization of non-market goods in order to make them comparable to market goods (*Improved Methods for Assessing Social, Cultural, And Economic Effects of Transportation Projects*, NCHRP 8-36-66, includes a good discussion). For example, in a BCA, the reduction in air pollution from a new technology can be monetized to find a value for implementing the technology in order to compare it to the costs of its implementation.

Throughout each of these reports, travel time savings, changes in crashes and changes in vehicle operating costs are listed as the primary, if not the only, direct impacts for state and local practitioners to consider in a BCA. GAO-05-172 has one of the simpler statements: “The key categories of potential direct user benefits from highway investments include travel-time savings, reductions in crashes, and reductions in vehicle operating costs.” (GAO, page 12) Other standard benefits can include reductions in agency costs, positive externalities, and incremental consumer surplus from new trips.

NCHRP Report 786 *Assessing Productivity Impacts of Transportation Investments* is intended to develop a methodology for incorporating productivity gains into an economic analysis, a new topic in transportation economics. This report mentions that productivity impacts should be, but seldom have been, included in traditional BCA models. The authors believe reliability, accessibility, and intermodal connectivity are all user benefits that can and should be included in a BCA. Since some measures already included in a BCA include some portions of productivity the report states that the unmeasured portion must be taken into account by following three actions. Those three actions are changing the definition of user to include shippers of freight, incorporating reliability as a benefit category, and including market access and connectivity effects such as economies of scale gained through access to a larger consumer base.

### How Is BCA Used in Planning for Operations?

BCAs give a sense of whether the project’s benefits justify the costs incurred. As such, it is a vital component in the decision making process that helps decision makers decide whether a project or an operational change is worth the investment. A BCA also allows for a comparison across projects whether these are infrastructure or technology based. This ensures that the best projects and investments out of the alternatives are selected for investment. FHWA has routinized the analysis of operations projects with its TOPS-BC tool (see http://www.ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm).

Due to the BCAs flexibility in meeting the needs of the decision makers, it can be a powerful tool for projects and investments of any size and scope. A BCA can be performed on a high-level basis to give a feel of what the basic costs and benefits may be, or a more thorough approach can be used that would give further details in what the impact of the project may be.

### How Can BCA for V2I Technologies Be Integrated with BCA for More Traditional Strategies?

BCAs have become a mainstream part of the planning stages of transportation projects. Many agencies have established guidelines and procedures to follow in the decision-making process that includes a relative assessment of an improvement’s costs and benefits. Similar to the integration of the Transportation Systems Management and Operations guidelines laid out in FHHWA’s Operations Benefit/Cost Analysis Desk Reference, there are some steps planners can take when integrating BCA for V2I technologies with more traditional strategies:

* Be sure to promote consistency and comparability across results;
* Structure the process to ensure familiarity to planners and decision makers;
* Encourage adoption of objectives and performance measures compatible with V2I technologies;
* Develop new traffic datasets or a new way to capture data needed for analysis specific to V2I technologies;
* Promote changes to the current analysis framework, benefit valuations and modeling capabilities of the planners and decision makers to allow an enhanced measurement of costs and benefits related to the technology;
* Allow for flexibility and adaptability within existing structure and policy.

Agencies are already familiar with the BCA process will find it easier to tailor the BCA approach specifically to V2I technologies than developing a new approach. However, they should be careful to make sure that their existing models can be adapted to issues unique to V2I applications (see discussion “What Makes Connected Vehicles Different from Other ITS Investments, and the Implications for Estimating Benefits?,” on page 6), making it difficult to integrate BCAs for V2I technologies with BCAs modeled for more traditional strategies.

Data needs may also be different between V2I technology and more traditional strategies. While traditional strategies have been in use for years and data regarding their impacts recorded, many V2I technology applications have just recently been deployed. With this in mind, data used for V2I BCAs may be limited and BCAs may need to be based on data collected from more traditional strategies.

### Challenges and Limitations

There are some commonly acknowledged limits to BCA. Much like other methods of economic analysis, BCA can lead to miscalculated results if not properly conducted. An unrealistic base case can lead to overly attractive alternatives, while a lack of realistic alternatives may leave the most beneficial decision non-existent within the framework of the analysis. Combining multiple projects into one singular project could potentially lead to the benefits of one project covering the costs of another or vice versa. This could lead to both projects following a similar path of rejection or acceptance when in reality only one should be accepted or rejected. Not correctly calculating the costs or benefits associated with certain aspects of the project may lead to an incorrect benefit-cost ratio making the project look much more attractive or unappealing than it really is.

As noted in NCHRP 8-36-66, the monetization of non-market goods is often criticized due to the fact that it does not take into account the difference between ethical values placed on non-market goods and monetary values (such as lowering emissions near a hospital or school). This makes estimating the “value” of these effects very difficult and subject to much debate and disagreement.

GAO’s summary from its expert panel, *The Benefits and Costs of Highway and Transit Investments*, among others, notes that BCA is also limited by the fact that land-use evaluation can be difficult to estimate using traditional BCA techniques, and the fact that transportation data currently in use by state and local transportation agencies limit the usefulness of BCA as it makes predicting patterns and trends difficult. Surveys of travel habits are too expensive for local transportation agencies which must rely on outdated or static data (i.e., traffic flow at a single time of day instead of throughout the day) to model future transportation needs.

In addition, in most cases, BCA does not take into account any equity considerations of who receives the benefits, which may or may not align with community goals (NCHRP Synthesis, p 21; GAO-05-423SP).

A quick overview of the advantages and disadvantages associated with BCA’s is highlighted below in Table 3.

Table 3: Advantages and Disadvantages of BCA

|  |  |
| --- | --- |
| **Advantage** | **Disadvantage** |
| * Well-known and established approach * Allows for estimation of net benefits (i.e., how much benefits exceed costs) * Consider all direct user benefits and agency costs of a project * Commonly used and well-established guidelines | * Dependent on quality of data used * Land use evaluation difficult to do * Does not account for potential difference in value on non-market goods and monetary values * Does not assess costs and benefits by beneficiary groups * Does not incorporate equity considerations * Does not typically include consideration of jobs, wages which are often of interest to local and regional policymakers |

## Economic Impact Analysis

### What is it?

Economic impact analysis examines indirect, local economic impacts of an investment (such as a new road) or policy intervention (such as geographic-based tax incentives). The results can be estimates of changes in jobs, tax revenue, wages, output, property values and even changes in tourism, housing and migration patterns.

As used by the dozen guides and reports reviewed here, EIAs are conducted at least partly with estimates of the direct impacts of the project, usually computed via a BCA. A prominent example is the FHWA’s *Economic Analysis* *Primer,* which states that many of the direct effects found in a BCA are also found in an EIA as an indirect effect (page 33). As an example, the *Primer* describes that the travel savings from a large project estimated in a BCA may encourage employees to live further away from their place of employment causing housing prices to rise for remote properties, which would be found in an EIA.

NCHRP 786 notes that a growing number of state agencies are now using EIA with a dynamic forecasting model in order to assess proposed transportation projects (page 29). These models, like regional travel demand models, are customized to a particular area. NCHRP 786 states that regional macroeconomic impact models treat business transportation cost savings as a reduction in business operating cost, which effects productivity, while household transportation costs are treated as a shift in consumer spending patterns, which does not affect productivity. These changes in business operating costs are often derived from a BCA, using data on the projected changes in travel due to the project. NCHRP 786 uses the term “standard traveler benefit” analysis (STB) to refer to “impacts directly experienced by travelers using the transportation,” also called “user benefits or transportation system efficiency benefits,” and which “include mobility benefits (travel time savings), vehicle operating cost savings (covering fuel consumption and vehicle wear) and safety improvements. . . .” (page 43).

***Where do I find help on preparing an EIA for my project?***

* *See FHWA’s Economic Analysis Primer, 2003; NCHRP’s Guidebook for Assessing the Social and Economic Effects of Transportation Projects [*[*http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp\_rpt\_456-a.pdf*](http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_456-a.pdf)*]; or NCHRP’s Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners [*[*http://statewideplanning.org/wp-content/uploads/NCHRP-08-36-101.pdf*](http://statewideplanning.org/wp-content/uploads/NCHRP-08-36-101.pdf)*].*
* *See Chapter IV “V2I Benefits Estimation Tool” starting on page 49.*
* *Use the V2I Benefits Estimation tool for estimating the local, regional, and state-wide economic impacts of connected vehicle to infrastructure deployments developed with the desk reference*
* *Other available tools include:*
  + *IMPLAN (IMpact analysis for PLANning).* [*http://www.implan.com/*](http://www.implan.com/)
  + *Regional Economic Models, Inc. (REMI).* [*http://www.remi.com/*](http://www.remi.com/)
  + *Transportation Economic Development Impact System (TREDIS). www.tredis.com*

Many of the reports reviewed acknowledged that the results of an EIA, frequently presented in terms of jobs, wages, and tax revenue, are often much more appealing to local decision makers and non-technical stakeholders, including local residents and their representatives than BCA results. In particular, FHWA’s *Economic Analysis* *Primer* and GAO’s report GAO-05-172 discussed the relative attractiveness of EIA results.

*… officials at the locations we visited indicated that they often based their decision about whether to proceed primarily on the project’s perceived indirect benefits, such as desirable changes in land use or economic development, which are difficult to forecast and were generally not quantified or systematically analyzed in the planning documents we reviewed.* (GAO, page 4)

Both reports refer to EIA results derived from BCA, which acknowledges the link between the two types of analyses. BCA estimates the direct transportation benefits (travel time, mobility, crash rates, operating costs, etc.) that are then used in the estimation of changes in economic activity, which is what an EIA seeks to estimate. That is, BCA estimates must be made before an EIA can be performed.

*… indirect economic impacts measured by EIA based on BCA results are of major interest to decision makers, planners, and the public, especially for large projects that are expected to generate major direct transportation benefits and costs*. (FHWA’s *Economic Analysis* *Primer*, page 32).

NCHRP 466 focuses on estimating indirect effects caused by transportation projects, one of the few accessible guidance documents to do so in detail. It is designed to give state and local planners guidance on how to assess the indirect effects of transportation projects so as to meet various federal requirements, including National Environmental Policy Act (NEPA) and Environmental Justice guidelines. Given the report’s focus on NEPA requirements, it provides information on a variety of analytical techniques, many of which can be time consuming and many of which do not include putting a dollar value on impacts.

### How is EIA Different from BCA?

Several key differences between BCA and EIA approaches were discussed in the reviewed federal and national reports on economic assessments for transportation. In particular, it was noted that BCA looks at net changes in the economy as a whole, whereas EIA examines impacts that may simply reflect a transfer of economic activity from one area to another, sometimes even areas within the same overall geographic unit being examined (such as a move from one location to another only 10 miles away). This change in location may, or may not be important as an overall priority in the community. If it is, then an EIA may be more appropriate, as long as the transfer of activity is understood.

This transfer issue is partly why FHWA’s *Economic Analysis* *Primer* recommends BCA as the primary analysis tool:

*As a matter of best practice, EIA results should be presented as a complementary analysis to the BCA. BCA results show whether a project is worth the resources that will be invested in it from a total social welfare standpoint. EIA results are helpful in informing decision makers and the public about how and in what form the benefits and costs of the project will ultimately be distributed within the economy*. (*Economic Analysis Primer*, page 34).

Another key difference between the two methods is the identification of the parties by the project. Whereas the BCA just shows the effects on the entire public, the EIA shows the effect on various parties, giving affected groups better information with which to raise their opinions on the project. It also helps in showing whether groups of particular concern, such as residents of a particular area, or regional freight transporters, are affected and by how much relative to other groups.

One more important difference between BCA and EIA, as discussed in NCHRP Report 786, is thatEIA focuses only on business impacts; it does not incorporate valuing societal impacts. BCA is the tool for estimating net societal impacts. This is a distinction which may be overlooked during local discussions focusing on benefits presented from an EIA.

### How is EIA Used in the Planning Process?

According to FHWA’s *Economic Analysis* *Primer*, EIA is best used as a complementary analysis to the BCA. The BCA support the decision-making process in determining whether a project is worth the resources while the EIA can help inform decision makers and the public on what form the costs and benefits will take and how they will be distributed. However, care should be taken in using these two types of analysis in conjunction with each other. The costs and benefits estimated by each method are not additive – they simply show the same costs and benefits in different forms.

### Challenges and Limitations for Economic Impact Analyses

Though EIA is a useful tool with many advantages, there are limitations. Table 4 details some of the advantages and disadvantages of EIA.

Table 4: Advantages and Disadvantages of EIA

|  |  |
| --- | --- |
| **Advantage** | **Disadvantage** |
| * Can estimate benefits by beneficiary group (public agency, industry, etc.) * Addresses jobs and wages, which are often of interest to local and regional policymakers | * Does not allow for estimating the “net” impacts or “net benefit of a project as often includes transfers between groups * Not as well known as BCA * Does not incorporate equity considerations |

## Other Approaches to Modeling Economic Development

The desk reference and tools are intended to specifically address a full range of benefits from V2I applications, including economic development, as feasible. Yet, as noted above, there does not seem to be a consensus on exactly what to measure under economic development, nor on any well developed and accessible methodologies for doing so. Thus, this desk reference includes an Appendix: Other Approaches to Modeling Economic Development which contains a discussion on other approaches to modeling economic development. It should be noted, though, that many state, local and regional planners may find these tools of somewhat limited use due to the time and expertise required to use them.

# 

# Connected Vehicles, V2I Applications, Deployment Scenarios, and Their Impacts (Agency, User, and Societal Benefits)

This section reviews recent reports on the benefits of V2I, including estimates of their magnitude of impact, methods used in estimation, who receives benefits, and the timeframe of analysis. In addition, this review focuses mostly on those aspects of CV deployment that are in the scenarios described in the AASHTO Footprint Analysis.

**Summary**

* To date, data on observed impacts of V2I applications is limited (see Table 6).
* Qualitative assessments of potential impacts are more extensive (see Table 7 through Table 12).
* CV benefit and BCA studies are summarized beginning on page 43.

The body of literature reviewed for this section ranges widely to encompass work in V2I applications, technologies, benefits, and cost assessments. Documents considered in this survey include those specifically called out by the authorizing scope of work, those found by more general searches of V2I web resources, and references supporting those primary sources. The literature is presented in a topical structure that prefigures the organizing principles for the desk reference and tools.

This desk reference recognizes multiple benefits to be considered, including travel time savings (mobility); travel cost savings; safety; travel reliability; environmental impacts; accessibility; equity; economic competitiveness; livability; short-term and long-term employment; industry activity; localized economic development benefits such as real estate values, household and business costs; as well as induced demand, system performance and agency costs.

This list includes impacts which would be classified as “direct” impacts as well as those which would be classified as “indirect” per the terminology generally used in the reports discussed in the previous section. Note that the indirect potential effects of V2I application and deployments originate from direct impacts on roadway users. For example, improved mobility and accessibility may lead to increases in real estate values or reduced business costs, as residents and business place a value on both due to travel time savings. In addition, direct impacts appear to be the most-studied type of benefits in the connected vehicle literature.

Among the existing V2I and other CV frameworks, two references stand out as potential models for structuring CV deployment: the Connected Vehicle Reference Implementation Architecture (CVRIA), which describes the relationships between CV applications and components, and the Footprint Analysis generated by ASHTO for FHWA which describes a likely deployment process and scenarios. These have guided our review of the literature and will direct the development of our framework.

As illustrated in Figure 1, stakeholder needs and funding directs the choice(s) of all types of CV components. These stakeholders, in turn, are the recipients of the benefits of CV deployments. This desk reference and it accompanying tool are intended help these stakeholders in their decision-making. At the same time, choices on CV components are partly determined by the requirements of different CV applications; and it is theses specific applications which generate the benefits of interest to stakeholders. These relationships and interdependencies will dictate the framework for the desk reference and tool approach and design concept.

Figure 1: Relationships among Connected Vehicle Components, Applications, Stakeholders, and Economic Benefits



This review of recent literature on CV impacts builds off an internal white paper prepared by economists at John A. Volpe National Transportation Systems Center, *Economic Benefits of Connected Vehicle Technologies (2014)*. This section includes additional examination of what was quantified and what could be incorporated into an accessible tool for state, local and regional practitioners.

The studies to date which seek to estimate the impacts of V2I technology have been constrained by the fact that deployment has been limited to a few test beds so far and available data is limited. Current analyses of the results from test beds in Michigan, Virginia and Arizona are also hampered by the lack of consensus on key assumptions such as rollout timing, likely penetration rates among vehicles and along roadways, ramp-up rates for technology adoption, among others.

The studies have also used various combinations of raw data and assumptions from various bodies of literature ranging from that on V2I to roadway ITS in general. Some used observed data from test beds in order to view the effects the technology had after implementation and then extrapolate this data out to the rest of the country. Data were also extracted from various databases to gain insight into how these technological changes could affect the safety, mobility and environmental issues faced and caused by today’s travelers. Other studies looked at prior literature in order to approximate the benefits V2I technology would have.

## V2I Applications and Deployment Scenarios Covered in This Reference

***Where do I find more information on CO-PILOT and AASHTO Near-Term Life-Cycle Costs for V2I Application Deployment Cost Estimation tool?***

* *For CO-PILOT got to: [*[*https://co-pilot.noblis.org/CVP\_CET/*](https://co-pilot.noblis.org/CVP_CET/)*]*
* *For AASHTO Near-Term Life-Cycle Costs obtain the tool on the FHWA website*

This desk reference and the accompanying V2I Benefits Estimation tool were designed to work with other USDOT sponsored tools to assist state and local agencies in assessing the potential benefits, cost, and economic development associated with implementing V2I technologies. Therefore, a consistent listing of V2I applications based on those in the FHWA-sponsored Cost Overview for Planning Ideas & Logical Organization Tool (CO-PILOT) and the AASHTO Near-Term Life-Cycle Costs for V2I Application Deployment Cost Estimation tool are used in this effort.

A list of these applications, taken directly from CO-PILOT and grouped by type, is provided in Table 5.

Table 5: Listing of CO-PILOT V2I Applications

|  |  |
| --- | --- |
| **APPLICATION** | |
| **Agency Data** | |
|  | CV-enabled Origin-Destination Studies - Cellular (ODS) |
|  | CV-enabled Turning Movement and Intersection Analysis - DSRC (TMIA) |
|  | Probe-based Pavement Maintenance - Cellular (PBPM) |
|  | Probe-enabled Traffic Monitoring - Cellular (PETM) |
|  | Vehicle Classification-based Traffic Studies - DSRC (VCTS) |
|  | Work Zone Traveler Information - Cellular (WZTI) |
| **Environment** | |
|  | AFV Charging-Fueling Information - Cellular (AFVCFI) |
|  | Connected Eco-Driving - Cellular (CED) |
|  | Dynamic Eco-Routing - Cellular (DER) |
|  | Eco-Approach and Departure at Signalized Intersections - DSRC (EADSI) |
|  | Eco-Cooperative Adaptive Cruise Control - DSRC (ECACC) |
|  | Eco-Lanes Management - Cellular (ELMC) |
|  | Eco-Lanes Management - DSRC (ELMD) |
|  | Eco-Ramp Metering - DSRC (ERM) |
|  | Eco-Smart Parking - DSRC (ESP) |
|  | Eco-Speed Harmonization - DSRC (ESH) |
|  | Eco-Traffic Signal Priority - DSRC (ETSP) |
|  | Eco-Traffic Signal Timing - DSRC (ETST) |
|  | Eco-Traveler Information - Cellular (ETI) |
|  | Low Emissions Zone Management - DSRC (LEZM) |
|  | Wireless Inductive-Resonance Charging (WIRC) |
| **Mobility** | |
|  | Advanced Traveler Information System - Cellular (ATIS) |
|  | Connection Protection - Cellular (T-CONNECT) |
|  | Cooperative Adaptive Cruise Control - DSRC (CACC) |
|  | Drayage Optimization - DSRC (DO) |
|  | Dynamic Ridesharing - Cellular (D-RIDE) |
|  | Dynamic Speed Harmonization - DSRC (SPD-HARM) |
|  | Dynamic Transit Operations - Cellular (T-DISP) |
|  | Emergency Communications and Evacuation - Cellular (EVAC) |
|  | Emergency Vehicle Preemption - DSRC (PREEMPT) |
|  | Freight Signal Priority - DSRC (FSP) |
|  | Freight-Specific Dynamic Travel Planning and Performance - DSRC (FSDTPP) |
|  | Incident Scene Pre-Arrival Staging Guidance for Emergency Responders - DSRC (RESP-STG) |
|  | Incident Scene Work Zone Alerts for Drivers and Workers - DSRC (INC-ZONE) |
|  | Intelligent Traffic Signal System - DSRC (I-SIG) |
|  | Mobile Accessible Pedestrian Signal System - DSRC (PED-SIG) |
|  | Queue Warning - DSRC (Q-WARN) |
|  | Transit Signal Priority - DSRC (TSP) |
| **Road Weather** | |
|  | Enhanced MDSS - Cellular (EMDSS) |
|  | Motorist Advisories and Warnings - Cellular (MAW) |
|  | Vehicle Data Translator - Cellular (VDT) |
|  | Weather Response Traffic Information - DSRC (WxTINFO) |
| **Smart Roadside** | |
|  | Smart Truck Parking - DSRC (STP) |
|  | Wireless Inspection - DSRC (WI) |
| **V2I Safety** | |
|  | Curve Speed Warning - DSRC (CSW) |
|  | Pedestrian in Signalized Crosswalk Warning - DSRC (PSCWT) |
|  | Red Light Violation Warning - DSRC (RLVW) |
|  | Reduced Speed-Work Zone Warning - DSRC (RSWZW) |
|  | Spot Weather Impact Warning - DSRC (SWIW) |
|  | Stop Sign Gap Assist - DSRC (SSGA) |
| **V2V Safety** | |
|  | Blind Spot-Lane Change Warning - DSRC (BSW-LCW) |
|  | Do Not Pass Warning - DSRC (DNPW) |
|  | Emergency Electronic Brake Lights - DSRC (EEBL) |
|  | Forward Collision Warning - DSRC (FCW) |
|  | Intersection Movement Assist - DSRC (IMA) |
|  | Left Turn Assist - DSRC (LTA) |
|  | Vehicle Turning Right in Front of Bus Warning - DSRC (VTRFBW) |

While there are multiple deployment scenarios available to state and local agencies, this desk reference and VBET explicitly address the following:

* Deployment of a single application or multiple applications (up to 15);
* Deployment in commercial or non-commercial vehicles;
* Local or regional deployment.

## AASHTO Footprint Analysis

The AASHTO Connected Vehicle Field Infrastructure Footprint Analysis (Footprint Analysis), sponsored by the USDOT and Transport Canada, was developed to support transportation agency CV deployment decisions. Component tasks provided a vision document, applications analysis, deployment design concepts, deployment scenarios and preliminary footprint, and infrastructure cost analysis. The final report, which consolidates the task-level reports, consists of a vision for the national footprint; background for and current research on connected vehicle deployments; underlying assumptions; the applications analysis; the deployment concepts, the preliminary national footprint, including the value proposition, deployment objectives, context, scenarios, and experience to date; and a preliminary deployment and operations cost estimation.

The AASHTO applications analysis describes a broad range of applications in categories including V2I safety, mobility (for light vehicles and freight), environmental impacts, road weather, agency operations, land border crossings, and payment. Documentation of each application includes an indication of its infrastructural characteristics, communications, benefits versus level of deployment, and data needs. Concepts are focused on “settings” and describe how infrastructure might be deployed in each setting to enable a set of applications and operations. For example, CV deployment on urban arterials is envisioned to occur predominantly at signalized intersections, enabling a suite of intersection safety, mobility, and environmental applications for light, commercial, transit and emergency vehicles and pedestrians.

The deployment design highways would focus on a different set of largely mobility and environmental applications, with specialized deployments for freight and payment applications. The efficacy of any particular application in those settings would depend on the application and its communication needs, and the relative deployment levels of equipped vehicles and roadside infrastructure.

The AASHTO deployment scenarios built on the design concepts to describe how deployment might proceed geographically over time. The scenarios are predicated on a set of assumptions covering agency and automaker decisions, technology development, and the associated timelines. It is presumed that CV infrastructure deployment planning will follow the same agency planning processes as are used for Intelligent Transportation Systems (ITS) and other roadway projects. Initial deployments are likely to occur around CV demonstration test beds and pilot demonstration sites and to spread along regional and national corridors of significance.

The AASHTO infrastructure cost analysis describes roadside equipment and associated deployment costs, including those for integrating with existing signal systems and ITS; back office systems development and deployment; communications, operations, maintenance and equipment replacement; and vehicle fleet and third-party traffic data. Much of this cost analysis was derived from the prior NCHRP 03-101 cost analysis of test bed deployment experience.

Discussion of benefits in the AASHTO analysis is limited to a general discussion of safety, mobility, environmental, and operational benefits. Economic development is not addressed.

## Connected Vehicle Reference Implementation Architecture (CVRIA)

The Connected Vehicle Reference Implementation Architecture (CVRIA) provides a framework for describing the CV environment. It describes the CV environment and the applications operating therein in four architectural views: an *enterprise view* of the relationships between organizations and stakeholder roles; a *functional view* of the logical interactions between functions; a *physical view* of the connections between physical objects, links and applications; and a *communications view* of the layered protocols between physical and application objects. Applications and components described in the AASHTO Footprint Analysis and other USDOT program descriptions are readily mapped to those in the CVRIA.

Applications in the CVRIA are drawn from a wide survey of CV program descriptions and are categorized as Environmental, Mobility, Safety, and Support types. Each application is described in detail with supporting systems engineering references. These application descriptions provide a reference implementation for which deployment benefits can be attributed.

The CVRIA physical view defines the potential components in a CV environment. The physical objects are categorized as center (e.g., Transit Management Center), field (e.g., (DSRC) Roadside Equipment), support (the Security and Credentials Management System), traveler (e.g., Personal Information Device), and vehicle (e.g., Commercial Vehicle On-board Equipment) objects. This physical view provides a reference implementation against which costs of deploying a CV environment can be allocated.

The CVRIA does not provide any documentation of application benefits or component costs.

## What Are the Impacts and Benefits of V2I Technologies?

The available body of V2I benefit-cost studies provides a broad view of applications that is generally supportive of continued development and deployment. The bases for and level of detail vary somewhat among the studies, however, and not all potential applications have been analyzed. In most cases the context for the analysis—the deployment location and stakeholders—is presumed to be inherent to the application and is not explicitly identified. Timeframes for deployment may or may not be specified, largely depending on whether a study is focused on aggregate benefits and costs or on specific performance indicator improvements. In addition, the categories of economic benefits that might be expected from V2I application deployments are not necessarily consistent across the studies. Table 6 summarizes the V2I benefit-cost studies currently available.

The categories of potential benefits used in Table 6 provide the framework used in for this desk reference. The V2I applications themselves generally align with certain classes of primary benefits—safety, mobility, environmental sustainability, and those accruing to agency operations. Other classes of benefits are not related directly to the type of application—vehicle operating costs and economic development. Benefits associated with particular performance measures may then be identified within each of the benefits categories.

Benefits descriptions within the literature also vary in the level of specificity. The most general case is to provide a non-quantified description of likely benefits in certain categories, indicated in Table 6 by a “D”. The more detailed analyses provide a quantification of benefits for applications in a particular category, indicated in Table 6 by a “Q”. In many cases the quantification is accompanied by a monetization of those benefits, indicated in the table by a “$”. References providing quantified and monetized benefits generally support those results with a description of the bases for the analysis, but one study (Cisco) provides only the monetized benefits.

Table 6: Summary of V2I Benefits Descriptions from BCA Literature

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Safety** | | | | **Mobility** | **Environmental Sustainability** | **Agency Benefits** | | **Vehicle Operating Costs** | | **Economic Development** | | |
| **General** | **Fatalities** | **Injuries** | **Property** | **Travel Time / Capacity** | **Reduced VMT / Emissions** | **Life Cycle Cost Reductions** | **O&M** | **Fuel Costs** | **Non-Fuel Costs** | **Land Use Changes** | **Accessibility** | **Property Values** |
| AASHTO Footprint  [FHWA-JPO-14-125] | D |  |  |  | D | D |  | D |  |  |  |  |  |
| NCHRP 03-101 |  |  |  |  |  |  |  | Q$ |  |  |  |  |  |
| AERIS  [various presentations] | D |  |  |  | Q$ | Q$ |  |  | Q$ |  |  |  |  |
| Volpe Briefing  [Volpe 2013] | Q$ |  |  |  |  |  |  |  |  |  |  |  |  |
| Volpe BCA  [Volpe 2008] | Q$ |  |  |  | Q$ | Q$ |  | Q$ |  |  | D |  |  |
| Road Weather  [FHWA-JPO-14-124] | Q$ | Q$ | Q$ | Q$ | Q$ | Q$ |  | Q$ |  |  |  |  |  |
| Noblis Mobility  [FHWA-JPO-13-004] |  |  |  |  | Q |  |  |  |  |  |  |  |  |
| Cisco  [Cisco 2011] | $ |  |  |  | $ | $ |  | $ | $ | $ |  |  |  |
| *Clarus*  [FHWA-JPO-11-116 through -120] | D |  |  |  | D |  |  | D |  |  |  |  |  |

Key: D – descriptive; Q – quantitative; $ - monetized  
Source: USDOT, Battelle/HDR/Synesis

As can be seen at a glance from Table 6, the most general categories of benefits—general safety, mobility, environmental sustainability, and agency operations and maintenance (O&M)—are represented in multiple analyses. The non-application-specific benefits—vehicle operating costs and economic development—have received much less attention, or are entirely missing from the body of literature. This is likely a result of the focus on connected V2I applications as a basis for deployment, and therefore for analysis. Absence of identified benefits in the table indicates only that the benefits were not described in the analysis, not necessarily that they are unavailable from any particular applications.

The summarization in Table 6 obscures, however, the further variability of the benefit and cost assessments among the applications described within the references and across the benefits categories. The Road Weather benefits analyses, for example, allocated the safety benefits specifically to reductions in fatalities, injuries, and property damage, and furthermore did so for specific road weather applications. This level of specificity will be needed by state, regional and local decision makers in their planning for V2I application deployment.

Table 7 through Table 12 below provide summaries of the potential benefits for particular V2I applications as identified in the literature surveyed in this desk reference. The list of applications is drawn from the CVRIA; it was in some cases necessary to map the application described in the literature to a similar CVRIA application. Benefits identification, where available, might be provided in a descriptive or quantitative form. Quantitative benefits are described in the table as in the literature, without attempting to translate those descriptions to a standardized categorization. The key stakeholders to whom benefits might accrue are also identified where available.

It is worth noting that none of the existing literature attempts to measure economic development impacts, either locally or regionally; only the direct impacts on users or agencies are estimated.

While researchers and practitioners generally agree that the benefits if V2I deployment will outweigh costs, the conclusion is based on data from a limited number of test beds supplemented by data from similar and related technology. Yet, some applications may not be net beneficial, at least in some cases. Additionally, these data have been used to estimate the dollar value of benefits, analyzed and presented based on limited applications. The use of this limited primary data is further hobbled by the fact that current analyses are based on several critical assumptions (such as penetration rates) which, with slight variations could lead to larger changes in final impacts. All in all, while there is a fair amount of early data, estimates of costs and benefits have not been formalized adequately nor made accessible enough to facilitate the justification of V2I investments at the state, local and regional levels.

Table 7: Environmental/AERIS/Sustainable Travel Application Benefits from the Literature

| **Application** | **Qualitative Benefits** | **Quantitative Benefits** | **Benefiting Stakeholders** |
| --- | --- | --- | --- |
| Connected Eco-Driving | energy savings, reduced travel time  [Feb2014 Webinar] | for the hypothetical freeway segment, connected eco-driving application (freeway speed harmonization with eco-driving principles) provides up to 4% fuel savings and more than 6% travel time reduction, depending on the traffic conditions; for arterial network (arterial speed harmonization with eco-driving principles and eco-approach/departure), around 5% fuel savings can be achieved but travel time increases by 2% [Feb2014 Webinar] | public |
| Dynamic Eco-Routing |  |  |  |
| Eco-Approach and Departure at Signalized Intersections | energy savings  [Pincus 2013] | 5-10% fuel savings for individual vehicles; only 1-3% if corridor already has coordinated signals [Pincus 2013] | public |
| Eco-Cooperative Adaptive Cruise Control | energy savings, reduced emissions  [July 2014 Webinar] | energy and CO2 savings peak around 30% for 100% penetration rate; somewhat less with lower penetration rate (e.g., 15% savings at 40% penetration rate)  [Jul2014 Webinar] | public |
| Eco-Integrated Corridor Management Decision Support System |  |  |  |
| Eco-Lanes Management | energy savings, reduced emissions  [July 2014 Webinar] |  |  |
| Eco-Multimodal Real-Time Traveler Information | (see eco-lanes) |  |  |
| Eco-Ramp Metering | (see eco-lanes) |  |  |
| Eco-Smart Parking |  |  |  |
| Eco-Speed Harmonization | energy savings, reduced emissions  [July 2014 Webinar] | maximum energy savings result in an approximate 8% to 10% reduction in mobility; typical energy savings in the range of 4% to 8% if mobility is kept the same  [Jul2014 Webinar] | public |
| Eco-Traffic Signal Timing | energy savings  [February 2014 Webinar] | 4% to 5% improvement in fuel consumption and environmental measures at full connected vehicle penetration, while a 1% to 4% at partial connected vehicle penetration in a fully coordinated network  [Feb2014 Webinar] | public |
| Eco-Transit Signal Priority | energy savings  (February 2014 Webinar] | improves the level of emissions and fuel consumption by about 1% to 2%; travel time improvements were observed in many of the scenarios, on the order of 1% to 3%  [Feb2014 Webinar] | transit, public |
| Electric Charging Stations Management |  |  |  |
| Low Emissions Zone Management | energy savings, reduced emissions  [September 2014 Webinar] | 3% to 5% energy and emissions savings at modest levels of eco-vehicle penetration coupled with enhanced transit services  [Sep2014 Webinar] | public |
| Roadside Lighting | energy savings  [NCHRP 03-101] | estimated that a lighting system can be dimmed 50% for at least 50% of the system burn timer, resulting in a 25% energy savings in the lighting system operations cost  [NCHRP 03-101] | agency |

Source: Battelle/HDR/Synesis, USDOT

Table 8: Environmental/Road Weather Application Benefits from the Literature

|  |  |  |  |
| --- | --- | --- | --- |
| **Application** | **Qualitative Benefits** | **Quantitative Benefits** | **Benefiting Stakeholders** |
| Enhanced Maintenance Decision Support System | reduced cost  of winter maintenance [FHWA-JPO-13-047] | few crashes avoided (property damage, injuries, fatalities)  [FHWA-JPO-14-124] | agency |
| Road Weather Advisories and Warnings for Motorists | reduced crashes, reduced injuries, reduced fatalities; reduced delays (improved routing)  [FHWA-JPO-13-047] | many crashes avoided (property damage, injuries, fatalities)  [FHWA-JPO-14-124] | public |
| Road Weather Information and Routing Support for Emergency Responders | reduced response times (notification and routing)  [FHWA-JPO-13-047] | no crashes avoided (property damage, injuries, fatalities)  [FHWA-JPO-14-124] | emergency responders |
| Road Weather Information for Freight Carriers | reduced crashes; reduced freight delays (improved routing), reduced weather-related restrictions  [FHWA-JPO-13-047] | few crashes avoided (property damage, injuries, fatalities)  [FHWA-JPO-14-124] | freight |
| Road Weather Information for Maintenance and Fleet Management System | improved agency resource utilization  [FHWA-JPO-13-047] | potential reduced equipment investment, reduced operating expenses  [FHWA-JPO-14-124] | agency |
| Variable Speed Limits for Weather-Responsive Traffic Management | reduced crashes, reduced injuries, reduced fatalities; reduced delays  [FHWA-JPO-13-047] | some crashes avoided (property damage, injuries, fatalities)  [FHWA-JPO-14-124] | public |

Source: Battelle/HDR/Synesis, USDOT

Table 9: Mobility Application Benefits from the Literature

|  |  |  |  |
| --- | --- | --- | --- |
| **Application** | **Qualitative Benefits** | **Quantitative Benefits** | **Benefiting Stakeholders** |
| [Border Management Systems](http://www.iteris.com/cvria/html/applications/app5.html#tab-3) |  |  |  |
| [Container Security](http://www.iteris.com/cvria/html/applications/app9.html#tab-3) |  |  |  |
| [Smart Roadside Initiative](http://www.iteris.com/cvria/html/applications/app94.html#tab-3) |  |  |  |
| [Freight Drayage Optimization](http://www.iteris.com/cvria/html/applications/app96.html#tab-3) | reduce freight demand | see Sect. 3.2 of ref. [FHWA-JPO-13-004] | CVO |
| [Freight -Specific Dynamic Travel Planning](http://www.iteris.com/cvria/html/applications/app32.html#tab-3) | reduced travel time, increased travel time reliability, increased freight capacity | 19-21% improvement in freight vehicle travel times  [FHWA-JPO-13-004] | CVO |
| [Ad Hoc Messages](http://www.iteris.com/cvria/html/applications/app3.html#tab-3) |  |  |  |
| [Performance Monitoring and Planning](http://www.iteris.com/cvria/html/applications/app88.html#tab-3) |  |  |  |
| [Advanced Automatic Crash Notification Relay](http://www.iteris.com/cvria/html/applications/app2.html#tab-3) | reduced emergency response time  [FHWA-JPO-13-004] |  |  |
| [Emergency Communications and Evacuation](http://www.iteris.com/cvria/html/applications/app30.html#tab-3) | reduced emergency response time  [FHWA-JPO-13-004] |  |  |
| [Incident Scene Pre-Arrival Staging Guidance for Emergency Responders](http://www.iteris.com/cvria/html/applications/app55.html#tab-3) | reduced emergency response time; reduced congestion around incident  [FHWA-JPO-13-004] |  |  |
| [Incident Scene Work Zone Alerts for Drivers and Workers](http://www.iteris.com/cvria/html/applications/app38.html#tab-3) | reduced secondary crashes; reduced emergency response time; reduced congestion around incident  [FHWA-JPO-13-004] |  |  |

Source: Battelle/HDR/Synesis, USDOT

Table 10: Mobility/Traffic Network and Signal Application Benefits from the Literature

|  |  |  |  |
| --- | --- | --- | --- |
| **Application** | **Qualitative Benefits** | **Quantitative Benefits** | **Benefiting Stakeholders** |
| Cooperative Adaptive Cruise Control | increased capacity (reduced headways); reduced congestion; reduced crashes  [FHWA-JPO-13-004] | 0-100% increase in capacity (freeways) depending on conditions; another study cited 60% [FHWA-JPO-13-004, FHWA-JPO-13-012, FHWA-JPO-13-011] | public |
| Queue Warning | reduced crashes; reduced congestion; travel time reduction; delay reduction  [FHWA-JPO-13-004] |  | public |
| Speed Harmonization | reduced congestion  [FHWA-JPO-13-004] | 0-20% improvement in travel times, 0-10.1% travel time reduction, 0-7% increase in throughput [FHWA-JPO-13-004, FHWA-JPO-13-012, FHWA-JPO-13-011] | public |
| Vehicle Data for Traffic Operations |  |  |  |
| Emergency Vehicle Priority | reduced EV response time, reduced secondary crashes  [FHWA-JPO-13-004] |  | public, safety responders |
| Freight Signal Priority | reduce arterial congestion (for freight) [FHWA-JPO-13-004] |  | CVO |
| Intelligent Traffic Signal System | reduce arterial congestion  [FHWA-JPO-13-004] | 25-41% delay reduction [Glassco], 36% travel time reduction [Fort Collins] / 14-19% delay reduction, 7-17% speed improvement [Syracuse] with respect to traffic control congestion; 60-70% delay reduction [Glassco] with respect to incident congestion; 30% reduction in travel times [VDOT] with respect to overall congestion | public, transit operators, CVO, safety responders |
| Pedestrian Mobility | reduce pedestrian injury/fatality |  | pedestrians |
| Transit Signal Priority | increased transit travel time reliability; reduce congestion through mode shift to transit [FHWA-JPO-13-004] |  | transit riders |
| Dynamic Ridesharing | reduce congestion through mode shift to transit [FHWA-JPO-13-004] |  | public |

Source: Battelle/HDR/Synesis, USDOT

Table 11: Mobility/Transit and Traveler Information Application Benefits from the Literature

|  |  |  |  |
| --- | --- | --- | --- |
| **Application** | **Qualitative Benefits** | **Quantitative Benefits** | **Benefiting Stakeholders** |
| Dynamic Transit Operations |  |  |  |
| Integrated Multi-Modal Electronic Payment |  |  |  |
| Intermittent Bus Lanes |  |  |  |
| Route ID for the Visually Impaired |  |  | public |
| Smart Park and Ride System |  |  | public |
| Transit Connection Protection | reduce congestion through mode shift to transit [FHWA-JPO-13-004] |  | public |
| Transit Stop Request |  |  |  |
| Advanced Traveler Information Systems | reduce congestion; reduce travel time; increase travel time reliability [FHWA-JPO-13-004] |  | public |
| Receive Parking Space Availability and Service Information |  |  | CVO |
| Traveler Information- Smart Parking | reduce congestion [FHWA-JPO-13-004] |  | public |
| Container/Chassis Operating Data |  |  | CVO |

Source: Battelle/HDR/Synesis, USDOT

Table 12: V2I Safety Application Benefits from the Literature

|  |  |  |  |
| --- | --- | --- | --- |
| **Application** | **Qualitative Benefits** | **Quantitative Benefits** | **Benefiting Stakeholders** |
| Transit Pedestrian Indication |  |  | transit, pedestrians |
| Transit Vehicle at Station/Stop Warnings |  |  |  |
| Vehicle Turning Right in Front of a Transit Vehicle |  |  |  |
| Curve Speed Warning | reduced crash rate at curves [FHWA-HRT-11-040] | potential 168,993 crashes annually [FHWA-HRT-11-040 Table 22] | public |
| Oversize Vehicle Warning |  |  |  |
| Pedestrian in Signalized Crosswalk Warning | reduced pedestrian injury/fatality at signalized crosswalk [FHWA-HRT-11-040] | potential 17,812 crashes annually [FHWA-HRT-11-040 Table 22] | pedestrians |
| Railroad Crossing Warning | reduced crash rate at railroad crossings [FHWA-HRT-11-040] | potential 1,314 crashes annually [FHWA-HRT-11-040 Table 22] | public |
| Red Light Violation Warning | reduced crash rate at signalized intersections [FHWA-HRT-11-040] | potential 234,881 crashes annually [FHWA-HRT-11-040 Table 22] | public |
| Reduced Speed Zone Warning | reduced crash rate [FHWA-HRT-11-040] | potential 360,695 crashes annually [FHWA-HRT-11-040 Table 22] | public |
| Restricted Lane Warnings |  |  |  |
| Spot Weather Impact Warning | reduced crash rate [FHWA-HRT-11-040] | potential 211,304 crashes annually [FHWA-HRT-11-040 Table 22] | public |
| Stop Sign Gap Assist | reduced crash rate at signed intersections [FHWA-HRT-11-040] | potential 278,886 crashes annually [FHWA-HRT-11-040 Table 22] | public |
| Stop Sign Violation Warning | reduced crash rate at signed intersections [FHWA-HRT-11-040] | potential 44,424 crashes annually [FHWA-HRT-11-040 Table 22] | public |
| Warnings about Hazards in a Work Zone | reduced crash rate in work zones [FHWA-HRT-11-040] | potential 86,611 crashes annually [FHWA-HRT-11-040 Table 22] | workers |
| Warnings about Upcoming Work Zone | reduced crash rate in work zones [FHWA-HRT-11-040] | potential 360,695 crashes annually [FHWA-HRT-11-040 Table 22] | public |

Source: Battelle/HDR/Synesis, USDOT

Quantifiable data from observed tests, pilots and studies is still limited for V2I applications; data were found for only some applications. These data and incorporated into VBET, and are summarized in Table 13. The impacts for specific applications made may have been gathered specifically for freeways or arterials, or more generally for all roadways. Ideally, the level of impacts would be measured separately for different road and vehicle types.

Table 13: Summary of Quantified Impacts of V2I Literature

| **Application** | **Value** | **Source** |
| --- | --- | --- |
| Connected Eco-Driving - Cellular (CED) | 6% travel time reduction [freeway]; 2% travel time increase [arterial] | Applications for the Environment: Real-Time Information Synthesis (AERIS) Program - Webinar Series: "Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results," 12 February 2014 |
| Connected Eco-Driving - Cellular (CED) | 4% fuel savings [freeway];  5% fuel savings [arterial] | Applications for the Environment: Real-Time Information Synthesis (AERIS) Program - Webinar Series: "Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results," 12 February 2014 |
| Cooperative Adaptive Cruise Control - DSRC (CACC) | 0-100% increase in capacity | Noblis, “Benefits of Dynamic Mobility Applications – Preliminary Estimates from the Literature”. Prepared for the USDOT ITS JPO, December 2012. FHWA-JPO-13-004.  SAIC, "Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO) – Assessment of Relevant Prior and Ongoing Research". Prepared for the USDOT ITS JPO, June 2012. FHWA-JPO-13-011.  SAIC, "Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO – Concept of Operations". Prepared for the USDOT ITS JPO, June 2012. FHWA-JPO-13-012. |
| Curve Speed Warning - DSRC (CSW) | Potential to reduce crashes | Vanasse Hanger Brustin, Inc., “Crash Data Analyses for Vehicle-to-Infrastructure Communications for Safety Applications”. Prepared for Office of Safety Research and Development, Federal Highway Administration, November 2012. FHWA-HRT-11-040. |
| Drayage Optimization - DSRC (DO) | 20% reduction in the number of bobtail (one-way) local drayage runs | Noblis, “Benefits of Dynamic Mobility Applications – Preliminary Estimates from the Literature”. Prepared for the USDOT ITS JPO, December 2012. FHWA-JPO-13-004. |
| Dynamic Speed Harmonization - DSRC (SPD-HARM) | 0-20% reduction in travel time | Noblis, “Benefits of Dynamic Mobility Applications – Preliminary Estimates from the Literature”. Prepared for the USDOT ITS JPO, December 2012. FHWA-JPO-13-004.  SAIC, "Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO – Concept of Operations". Prepared for the USDOT ITS JPO, June 2012. FHWA-JPO-13-012. |
| Dynamic Speed Harmonization - DSRC (SPD-HARM) | 2-30% reduction in crashes | Noblis, “Benefits of Dynamic Mobility Applications – Preliminary Estimates from the Literature”. Prepared for the USDOT ITS JPO, December 2012. FHWA-JPO-13-004.  SAIC, "Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO) – Assessment of Relevant Prior and Ongoing Research". Prepared for the USDOT ITS JPO, June 2012. FHWA-JPO-13-011.  SAIC, "Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO – Concept of Operations". Prepared for the USDOT ITS JPO, June 2012. FHWA-JPO-13-012. |
| Dynamic Speed Harmonization - DSRC (SPD-HARM) | 0-7% increase in throughput | Noblis, “Benefits of Dynamic Mobility Applications – Preliminary Estimates from the Literature”. Prepared for the USDOT ITS JPO, December 2012. FHWA-JPO-13-004. |
| Eco-Approach and Departure at Signalized Intersections - DSRC (EADSI) | 5-10% fuel savings (only 1-4% if corridor already has coordinated signals) | Pincus, Marcia, “Applications for the Environment: Real Time Information Synthesis (AERIS)”, Presented at the USDOT Connected Vehicle Public Meeting, Arlington, VA, September 2013. |
| Eco-Cooperative Adaptive Cruise Control - DSRC (ECACC) | 10-30% fuel savings | Applications for the Environment: Real-Time Information Synthesis (AERIS) Program - Webinar Series: "Eco-Lanes: Preliminary Modeling Results," 23 June 2014. |
| Eco-Speed Harmonization - DSRC (ESH) | Up to 12% savings with 8% reduction in mobility; 4-8% savings with no mobility impact | Applications for the Environment: Real-Time Information Synthesis (AERIS) Program - Webinar Series: "Eco-Lanes: Preliminary Modeling Results," 23 June 2014. |
| Eco-Traffic Signal Timing - DSRC (ETST) | 1-3% travel time improvement | Applications for the Environment: Real-Time Information Synthesis (AERIS) Program - Webinar Series: "Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results," 12 February 2014. |
| Eco-Traffic Signal Timing - DSRC (ETST) | 1-2% fuel savings | Applications for the Environment: Real-Time Information Synthesis (AERIS) Program - Webinar Series: "Preliminary Eco-Traffic Signal Priority (for Transit and Freight) and Connected Eco-Driving Modeling Results," 12 February 2014. |
| Enhanced MDSS - Cellular (EMDSS) | 0.03% reduction in crashes | Booz Allen Hamilton, “Road Weather Connected Vehicle Applications: Benefit-Cost Analysis Interim Report”, Prepared for the USDOT ITS JPO, January 2013. FHWA-JPO-14-124. |
| Intelligent Traffic Signal System - DSRC (I-SIG) | 2-28% reduction in travel time | “City of Fort Collins Advanced Traffic Management System: Final Report”, RITA ITS JPO, EDL Number 14452, 24 June 2008.  Glassco, R., et al. “Studies of Potential Intelligent Transportation Systems Benefits Using Traffic Simulation Modeling: Volume 2”, Federal Highway Administration, U.S. DOT, June 1997.  Park, Byungkyu (Brian) and Yin Chen, “Quantifying the Benefits of Coordinated Actuated Traffic Signal Systems: A Case Study”, Virginia DOT, Report No. VTRC 11-CR2, September 2010. |
| Intelligent Traffic Signal System - DSRC (I-SIG) | 5-50% delay reduction | Glassco, R., et al. “Studies of Potential Intelligent Transportation Systems Benefits Using Traffic Simulation Modeling: Volume 2”, Federal Highway Administration, U.S. DOT, June 1997.  Park, Byungkyu (Brian) and Yin Chen, “Quantifying the Benefits of Coordinated Actuated Traffic Signal Systems: A Case Study”, Virginia DOT, Report No. VTRC 11-CR2, September 2010. |
| Motorist Advisories and Warnings - Cellular (MAW) | 4% reduction in crashes | Booz Allen Hamilton, “Road Weather Connected Vehicle Applications: Benefit-Cost Analysis Interim Report”, Prepared for the USDOT ITS JPO, January 2013. FHWA-JPO-14-124. |
| Road Weather Information and Routing Support for Emergency Responders | 0.0003% reduction in crashes | Booz Allen Hamilton, “Road Weather Connected Vehicle Applications: Benefit-Cost Analysis Interim Report”, Prepared for the USDOT ITS JPO, January 2013. FHWA-JPO-14-124. |
| Road Weather Information for Freight Carriers | 0.0516% reduction in crashes | Booz Allen Hamilton, “Road Weather Connected Vehicle Applications: Benefit-Cost Analysis Interim Report”, Prepared for the USDOT ITS JPO, January 2013. FHWA-JPO-14-124. |

Source: Battelle/HDR/Synesis, USDOT

## Connected Vehicle Benefit and BCA Studies

Studies of the benefits, including full BCAs, of the CV environment to date have been sponsored by particular CV programs to address specific sets of applications. The resulting body of literature is therefore diverse in its application context and in its perspective on potential costs and benefits. There has been much less attention to how those benefits and costs aggregate across a field of deployment. Multiple applications may claim to be creating benefits based on the same performance measures, but few studies have addressed benefits in deploying multiple applications. Components needed for many or all applications are included in each study with their associated costs without necessarily describing cost sharing across application deployments. Studies are summarized here according to their application set perspective. Since the purpose of the survey is to identify potential sources of V2I application benefit and cost data for further analysis, the summaries generally indicate the types of results available in the study, but do not necessarily provide numeric results.

### NHTSA Analysis of V2V Readiness

The lead-up to the 2013 NHTSA decision to pursue rulemaking for deployment of wireless communications in light vehicles included substantial technical and policy analysis of the means and effectiveness of those communications in improving vehicle-to-vehicle safety. Much of that analysis was documented in the V2V Readiness study. Topics addressed in the study include the background of V2V technology; a description of the safety need; the scope and legal authority for potential NHTSA action; assessment of technical practicability of V2V communications; descriptions of potential V2V applications; public acceptance considerations; privacy considerations; communications security; legal liability; detailed cost estimates of V2V implementation; and (finally) preliminary effectiveness and benefits estimates of V2V safety applications.

The V2V Readiness study is intentionally focused on V2V safety applications of CV technology, and does not specifically address V2I applications in any context. Nonetheless, the overall approach and selected elements of the study are useful references for V2I studies. The cost analysis provides a detailed breakdown of vehicle component costs not found in any similar V2I work. Roadside equipment cost was assessed, but only in the context of supporting communications security, ignoring deployments for any V2I applications. The benefits analysis provides a similarly detailed assessment of target crashes for V2V applications, but does not address V2I crashes. The benefits assessment also provides an evaluation of the effectiveness of V2V technology in mitigating the consequences of target crashes based on a safety simulation of intersection movement assist (IMA) and left turn assist (LTA) applications.

*Study Highlights*

* *Contains detailed analysis of vehicle costs of deployment not found in other V2I references*
* *Addresses benefits of only V2V applications*

### Volpe Studies

The Volpe National Transportation Systems Center has produced several reference CV benefit-cost publications. A 2013 briefing described the increasing sophistication of estimates of the potential benefits. Whereas early approaches estimated the maximum potential safety benefits for V2V and V2I crash scenarios, the more recent work evaluates that potential for V2I in conjunction with varying roadside equipment (RSE) deployment scenarios. The models incorporate a range of time-dependent deployments of built-in and retrofit vehicle on-board equipment (OBE), and similar time-dependent RSE deployments. This analysis also uniquely attempts to assess optimal RSE siting based on actual crash location statistics from the State of Missouri. Cost estimates for individual RSE deployment were drawn from the same source as the NHTSA V2V Readiness study. Results of the study provide crashes avoided (assuming 100% effectiveness) and monetized net benefit potential.

*Study Highlights*

* *Describes time-dependent V2I costs and benefits for safety applications*
* *Assumes a particular DSRC geographic deployment model*

An earlier 2008 Volpe benefit-cost analysis provided a broader view of the potential CV application, but was based on much less specific deployment assumptions available at the time. Applications considered in the study covered V2I safety and mobility, but were not defined as specifically as those in the more recent USDOT program systems engineering documents, the CVRIA, and the AASHTO Footprint Analysis. Benefits were estimated for each of the applications; costs were estimated for major classes of cost components based on assumptions and information available at that time. Results are presented in terms of system performance metrics (crash reductions and travel delay) and monetized benefit-cost.

*Study Highlights*

* *Broad analysis of V2I benefits and costs*
* *Based on preliminary application definitions since superseded by research captured in the CVRIA*

### Crash Data Analyses

Estimates of the safety benefits of connected vehicle applications are frequently based on the number of crashes that might be expected to be avoided. These studies have in many cases, like the 2013 Volpe briefing, based the potential benefits on the types of crashes as they might be characterized in a crash reports from the scene. A 2012 Crash Data Analysis for FHWA (FHWA-HRT-11-040), however, presented potential V2I safety benefits in terms of magnitude, characteristics and costs of crashes to be targeted by V2I safety applications. The study began with a review of prior crash data studies and of V2I safety applications. Applications addressed in this study addressed running a red light, running a stop sign, driver gap assist at signalized intersections, curve speed warnings, work zone warning for reduced speeds, spot treatment/weather conditions, speed zone warnings, work zone alerts for workers, and pedestrian detection. The study also investigated crash scenarios that are not specifically addressed by CV applications. Results of the analysis are presented in terms of the potential annualized number and monetized value of crashes avoided. The analysis did not estimate the effectiveness of applications (and assumed 100% effectiveness in its conversion from the potential number of crashes affected to economic benefits), and did not address any dependency of the application on the roll-out of CV technology over time. Costs for the safety applications were also not addressed.

*Study Highlights*

* *Identifies potential numbers of crashes affected by V2I safety applications*
* *Does not estimate the effectiveness of applications in mitigating crashes, time dependencies on deployment rate, or costs of applications*

A precursor of target crash frequencies performed by Volpe for NHTSA used a similar base set of crash data and covered both V2V and V2I crashes. It estimated the numbers of crashes for light and heavy vehicles that would be targeted by CV technology countermeasures. This is the source document for the frequent assertion in CV discussions that “80%” of crashes will be addressed or, incorrectly, avoided or prevented) by CV deployments. The study does not make any assertions about the specific applications that might be deployed, or about their effectiveness. The study also does not address deployment timelines or costs.

### NCHRP 03-101 BCA

The objectives of the NCHRP 03-101 study of the “Costs and Benefits of Public-Sector Deployment of Vehicle to Infrastructure Technologies” were to evaluate and document the benefits and costs of V2I technologies for agency decision support and to describe and document the state of DSRC technology development. The cost assessment was based on data from three CV demonstration test bed deployments in Michigan, Virginia, and Arizona. The cost categories were exclusively infrastructural, but included the full life cycle costs of acquisition, development, operations and maintenance. Cost components included the roadside equipment and backhaul communications from the roadside to back office systems. Benefits in this analysis were associated not with specific CV applications, but more generally with agency operations costs items. Benefits were estimated for crash cleanup cost reductions, work zone crash reductions, lower cost of pavement condition detection, adaptive lighting, and potential reductions in infrastructure required to monitor traffic. The net benefits and costs were then evaluated for each of the three deployment sites based on their specific cost data. Results indicate that the benefit-cost ratio is not greater than one for any of the sites over the first ten years of operations, but that trends would indicate increasing benefits over time.

*Study Highlights*

* *Describes benefit-cost analysis of applications addressing transportation agency operations and maintenance*
* *Costs are based on pilot demonstration deployments*

### AERIS Environmental Applications

The objective of the Applications for the Environment: Real-Time Information Synthesis (AERIS) is to create CV applications and associated technologies using real-time data that benefit the environment through reduction of emissions. AERIS applications generally resemble other CV applications intended to improve mobility, but are focused on energy savings and emissions reduction rather than reduced delay and travel times. For example, whereas speed harmonization attempts to relieve congestion and delay through proactive speed reductions ahead of the site of congestion, eco-speed harmonization uses the same type of speed reductions to optimize emissions reduction.

The 2012 AERIS benefit-cost analysis estimated the level of benefits available from the AERIS applications based on prior research into environmentally beneficial applications that did not explicitly depend on CV technology deployment. This approach allowed the study to look closely at potential benefits in terms of performance metric improvements (e.g., greenhouse gas, criteria pollutants, and fuel savings) and to monetize those benefits across the full suite of applications. The cost analysis presumed that the build-out of the baseline CV infrastructure and vehicle components were in place according to a deployment curve for other applications, and therefore only addressed those costs specifically attributable to AERIS applications. The benefits and costs were then scaled to a national deployment.

*Study Highlights*

* *Describes benefit-cost analysis of applications addressing environmental sustainability*
* *Benefits are based on simulation analyses of varying degrees of sophistication*

AERIS work since the 2012 benefit-cost analysis, as described in a series of webinars throughout 2013 and 2014, has taken a more focused look at each of the AERIS applications to reassess the potential benefits through a series of application simulations. Each simulation is based on real roadway facilities and associated performance characteristics. These simulations provide a degree of confirmation of the 2012 BCA, but also provide opportunities to assess the effects of assumptions and the interaction of applications. Specific performance metrics estimated in these simulations include emissions reductions, fuel/energy savings, capacity increases and reduced delay. Potential benefits trade-offs are acknowledged and estimated; for example, optimizing emissions reductions in some AERIS applications may reduce roadway segment capacity from its optimal values. Costs are not addressed in these simulations.

*Study Highlights*

* *Describes benefit-cost analysis of applications addressing road weather consequences*
* *Provides very detailed safety benefits derivation*
* *Notes costs of deployment that are specific to road weather applications*

### Road Weather Applications

A benefit-cost analysis of road weather connected vehicle applications was prepared for USDOT by Booz Allen Hamilton, published as an interim report in 2013, and presented at the 2012 Road Weather Management Stakeholder Meeting. The analysis was built around a set of road weather CV applications identified in a prior concept of operations document that are consistent with those found in both the CVRIA and the AASHTO Footprint Analysis. The study provides a detailed analysis of safety, operational, mobility and environmental benefits for each weather application. Both performance metric improvements and monetized benefits are identified. Costs are explicitly identified for RSE installation, operation and maintenance, and are estimated for weather application services. The study further identifies costs such as additional sensors and roadside equipment specific to weather applications.

### Mobility Applications

A 2012 report prepared for the USDOT ITS Joint Program Office by Noblis provides qualitative and preliminary quantitative estimates of CV mobility benefits drawn from other primary literature. The list of mobility applications described in the document is substantially the same as that drawn from similar sources for the CVRIA and the AASHTO Footprint Analysis. The benefits descriptions are provided in a detailed set of tables identifying both qualitative delay reduction benefits and quantitative mobility benefits for the priority applications. Key performance metrics for which benefits are drawn from primary sources include reductions in vehicle delay (both recurring and non-recurring), improvement in travel time reliability, capacity increase, speed increases. The document does not describe any of the cost bases or identify economic development opportunities. The bibliography provides an extensive set of primary sources for the benefits data (some of which are replicated in the bibliography here), and an appendix identifies “aspirational goals” for each application in terms of key performance measures.

*Study Highlights*

* *Describes benefit-cost analysis of applications addressing mobility*
* *Benefits are quantified, but not monetized*
* *Does not describe costs*

### Cisco CV Business Case

A 2011 white paper on “Connected Vehicles and Government” published by the Cisco Internet Business Solutions Group provides a private-sector commercial perspective on CV application benefit-cost analysis that is otherwise missing from the public-sector sponsored CV literature. The white paper provides a high-level economic analysis of a connected vehicle environment, starting with an assessment of U.S. vehicle and societal traffic costs, some of which it then links to the cost of congestion. The Cisco study then emphasizes vehicle-miles-traveled (VMT) revenue and demand mitigation as means to manage these costs and providing a “soft mandate” for vehicle connectivity that is not driven exclusively by safety benefits. The paper estimates the potential monetized benefit at $1400 per vehicle, divided amongst government/society, insurance carriers, automakers/dealers, and new “profit pools” for mobility apps and other location-based services. The cost assessment is built around DSRC RSE deployment and on infrastructure cost estimates from the 2008 Volpe study described earlier. The paper then discusses potential new business opportunities driven by deployment of RSEs, including tolling, optimizing roadway maintenance, and smart parking. It concludes with a discussion of the potential to use public-private partnerships (PPPs) as a means of (partially) funding the CV infrastructure deployment and suggests that distribution of even part of the $1400 in monetized benefits “could create 400,000 new jobs in the emerging connected vehicle industry in the United States.”

*Study Highlights*

* *Projects CV deployment benefits across broad economic categories*
* *Applications are not limited to transportation operations*
* *Provides monetized benefits without detailing underlying performance benefits*

The Cisco white paper differs from the public-sector CV benefit-cost analyses in a variety of ways that are both compelling and problematic. The CV applications suggested in the Cisco work are described in only broad terms such as safety and crash avoidance, pay-as-you-go insurance, tolling, smart parking, and such. This list covers a wider range of possibilities than have been covered in other literature that focuses exclusively on public-sector applications. With respect to benefits, the Cisco work takes a broader view, but does not provide any clear basis or evaluation. The largest component, attributed to government—fuel costs, emissions, and time in congestion—is presented as a single value. The RSE/infrastructure cost, taken from the 2008 Volpe study, could be updated. The discussion of the recovery of those costs through new business models, however, suggests economic opportunities that may not be adequately explored in the public-sector literature.

### Clarus and Road Weather Use Case Studies

The *Clarus* Initiative and the *Clarus* System were developed by FHWA’s Road Weather Management Program (RWMP) as a means of providing consistent access to road weather information for stakeholders across the country. The *Clarus* System collected, quality checked, stored, and published road weather information in a standard format that enabled sharing and reuse of the data in multiple applications. *Clarus* developed in parallel with CV technologies and eventually included mobile data from connected vehicles.

The RWMP further facilitated demonstration of *Clarus* applications in the form of a set of five use cases: Enhanced Road Weather Forecasting; a Seasonal Load Restriction Tool; a Non-Winter Maintenance Decision Support System; a Multi-State Control Strategy Tool; and Enhanced Road Weather Content for Traveler Advisories. Taken together, the *Clarus* use cases describe potential applications of the *Clarus* System and its road weather data integration capabilities, although it is not specifically a CV system. The *Clarus* use cases in many ways parallel the development of CV applications around CV data collection and integration, and many of the desired application outputs are common to related CV applications. Lessons learned from the *Clarus* use case concepts and demonstrations may help inform similar efforts in CV applications, but the qualitative benefits discussion for the use cases are only indirectly relevant to particular CV applications.

*Study Highlights*

* *Describe applications of road weather data in system operations*
* *Not specific to CV applications*
* *Describe only generalized benefits without any cost analysis*

# V2I Benefits Estimation Tool (VBET)

A user-friendly, computer-based tool was built to accompany this desk reference and assist state and local agencies in assessing the potential benefits and economic impacts associated with implementing V2I technologies. This tool –VBET– is a Microsoft Excel Workbook designed to work with the output of other FHWA supported V2I cost estimation and prioritization tools to support decision making for V2I deployment. The tool also allows the user to input local information about proposed V2I deployment and develop locally specific estimates of benefits.

**Summary**

* V2I Benefits Estimation Tool Overview provides a background on the tool and guidance on its use.
* Other Tools which can be used together with the V2I Benefits Estimation Tool: CO-PILOT; AASHTO Near-Term Life-Cycle Costs for V2I Application Deployment.

Since the tool includes detailed instructions within each worksheet to guide users, as well as separate help functionality, this chapter provides general direction and guidance and is not a comprehensive user guide for the tool.

## Tool Overview

VBET was developed as a Microsoft Excel Workbook and designed to support decision making for V2I deployment. It is similar in many ways to FHWA’s Tool for Operations Benefit-Cost Analysis (TOPS-BC), a tool designed to assist practitioners in conducting BCA for ITS applications, but VBET incorporates vehicle penetration rates and other assumptions critical for estimating the impacts of V2I deployments.

***Where do I find the V2I Benefits Estimation tool?***

* *The tool is available on   
  the FHWA website.*

VBET offers the user four key capabilities.

### Capability 1: Investigate Potential Impact of V2I Applications

The first key capability is an automated review of existing V2I research and potential impacts of V2I technologies.

### Capability 2: Identify Other Appropriate Economic Tools and Methods

The second key capability helps the user identify other appropriate economic tools and methods for conducting economic analysis of V2I applications, either BCA; EIA; or methods to support the analysis of economic development impacts.

### Capability 3: Conduct Economic Analysis of V2I Applications

The third key capability provided in this tool is the ability to conduct a sketch-planning level assessment of benefits for one or multiple V2I applications. It helps users to conduct a BCA or a simplified EIA for one or more V2I applications.

### Capability 4: Get Help

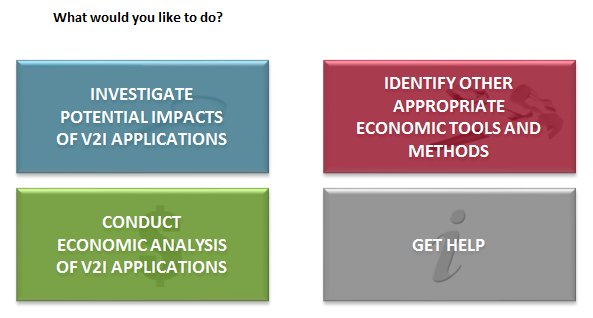
The fourth key capability of the tool is to serve as a reference guide.

## Using VBET

Like the TOPS-BC tool upon which it is based, VBET can be used on any computer equipped with Microsoft Excel 2010 or later.

Figure 2 presents a screen shot of the tool’s opening screen, which provides quick navigation to its capabilities.

Figure 2: VBET Tool Opening Screen



The worksheets within the tool are organized by capability and are color-coded according to the four main capabilities:

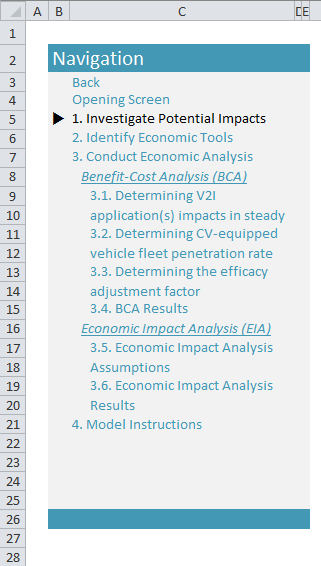
* **Blue – Capability 1: Investigate Potential Impact of V2I Application;**
* **Red – Capability 2: Identify Appropriate Economic Tools and Methods;**
* **Green – Capability 3: Conduct Economic Analysis of V2I Applications; and**
* **Gray – Capability 4: Get Help.**

There are two separate modes to facilitate using the tool by level of expertise:

* **Simple**. In this default mode, users see only those worksheets that require user inputs or present results. Users still have the option of adjusting key parameters (see subsection on Parameters, beginning on page 62).
* **Advanced.** Users can select to work using the advanced mode, which displays additional sheets with interim calculations as well as interactive sheets and model results.

The tool also has an option to “Show Entire Model,” which displays all the sheets including those with intermediate calculations. This feature may be useful for users who wish to examine the models internal structure, specific formulas, base sheets with tables of data from parameters used in calculations, and other internal aspects of the tool.

Figure : Screen View of the Tool Navigation Menu

The tool can be navigated by selecting the desired worksheet tabs within the workbook or by using a navigation bar imbedded on the side of each worksheet that allows the user to jump between sections of the model. An example of this navagation bar is shown in Figure 3.

### Using Capability 1: Investigate Potential Impact of V2I Application

The tool’s first capability allows practitioners to research and identify the potential high-level impacts of various V2I applications. The worksheet providing this capability allows the user to select a single V2I application at a time and associated impact categories that the user would like to research. Upon selecting these inputs, a range of observed impacts are displayed.

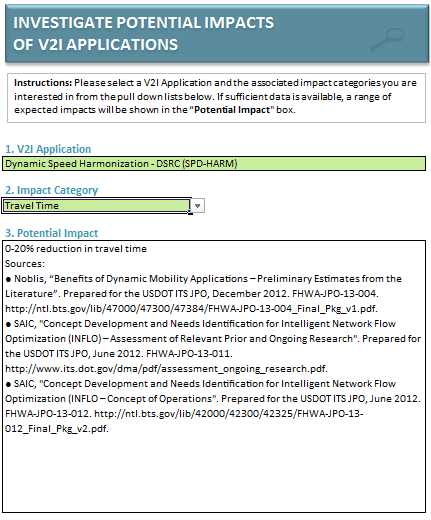
The V2I applications in the tool are the same as those in the FHWA-sponsored Cost Overview for Planning Ideas & Logical Organization Tool (CO-PILOT) and the AASHTO Near-Term Life-Cycle Costs for V2I Application Deployment Cost Estimation tool.

This capability complements another useful tool for planners and decision-makers considering V2I applications, AASHTO’s *Near-Term V2I Transition and Phasing Analysis Application Prioritization Tool*, which is available on the FHWA website. The Near-Term Application Prioritization Tool provides information on V2I applications based on user-specified needs. Users indicate what their goals are for implementing the improvement, what problem they are trying to solve, and what impacts they are trying to attain; the tool then recommends a short list of recommended V2I applications. Unlike VBET, Near-Term Application Prioritization Tool does not provide quantified benefits estimates, but it does include a comprehensive overview of types of benefits which can be expected from V2I applications.

The tool allows the user to input site-specific information about a proposed V2I deployment and estimate potential user benefits as well as economic impacts.

Clicking on the upper left button on the tool’s opening screen (see Figure 2, above), directs the user to a worksheet that allows the user to select a single V2I application at a time and one associated impact category that the user would like to research. Upon selecting these inputs, a range of observed impacts will be displayed under “Potential Impact.” An example of the impact lookup worksheet is shown in Figure 4.

Figure 4: Example of Potential Impacts of V2I Application Lookup Worksheet



The potential impacts of a given V2I application are drawn from an imbedded database that contains all the applications and their associated impacts for each measure of effectiveness, for which such information has been found. Much of the research to date has been qualitative for many applications, quantified impacts have been observed for only a few of the applications. Therefore, while the database is populated with findings from the literature described in this desk reference, it is designed to facilitate the addition of new evidence as deployments expand and new information becomes available.

### Using Capability 2: Identify Appropriate Economic Tools and Methods

The second capability helps users identify appropriate economic tools and methods for conducting economic analysis of V2I applications. As noted above, these tools and methods fall under the three main categories:

* Benefit-cost analysis (BCA);
* Economic impact analysis (EIA);
* Methods to support the analysis of economic development impacts, such as changes in property value.

Clicking on the upper right button on the tool’s opening screen (see Figure 2, above), directs the user to a worksheet with an interactive feature that allows the user to specify the impacts of greatest interest and then see which tools are most appropriate. Table 16, above on page 86, presents a summary of approaches and models to support the analysis of economic development impacts included in this feature.

### Using Capability 3: Conduct Economic Analysis of V2I Applications

The tool’s third key capability is the ability to conduct a sketch-planning level BCA or a simplified EIA for one or more V2I applications. The tool provides default values for impact parameters, performance relationships, and benefit valuations based on findings from the literature review. However, users have the capability to override each of these values.

Clicking on the lower left button on the tool’s opening screen (see Figure 2, above), directs the user to a worksheet with directions to choose the method of analysis, either BCA or EIA. At this worksheet, the user is directed to a pull-down menu with a listing of the V2I applications included. Once the user selects the application(s) to be analyzed, the tool will invite the user to determine the type of economic analysis to be run:

* Conduct a benefit-cost analysis (BCA); or
* Conduct an economic impact analysis (EIA).

The section below outlines how the two choices work and how to use them.

###### Conduct Benefit-Cost Analysis

The tool will assist the user to input cost information, refine input and other parameters if more robust data are available (such as specific to a particular corridor or community), as needed to estimate the benefits and costs.

Users can estimate the costs and impacts for the deployment of a single application, or multiple applications (up to 15) over the same time period. The tool directs the user to choose the application(s) for analysis, specific the timeframe for analysis and other key parameters. Default values are available for use.

The subsection below outlines how the tool conducts the BCA.

##### Incorporating Costs

Estimating the costs of a V2I investment can be very complex compared to a more traditional infrastructure improvement. The tool includes the following cost categories:

* Capital Costs or Upfront Costs: Include all capital and upfront costs need to produce and install equipment related to the selected V2I application(s);
* Operation and Maintenance Costs: Include continuous costs throughout the analysis period used to operate and maintain the selected V2I application(s); and
* Renewal and Replacement Costs: Include the periodic costs of replacing the system equipment as it reaches its expected useful life, which may be shorter than the analysis period selected for the BCA.

The user will need to extract cost information from external sources, but the tool has been designed with placeholders for the various cost components of the selected V2I application(s). Upfront costs can be taken from the AASHTO *Near-Term V2I Transition and Phasing Analysis Life Cycle Cost Model Tool*, which is available on the FHWA website. This tool investigates V2I life-cycle cost analysis, or estimated independently by the users. The worksheet provides imbedded instructions on how to pull in cost data.

##### Benefits Estimation

Benefits are calculated beginning the year after construction is completed and for the remaining number of years into the future that have been specified for the overall analysis.

In any given year, each benefit associated with a V2I application is calculated through the following steps:

* Step One – Determining V2I application(s) impacts in steady state: The potential impact of a given V2I application is drawn from an imbedded database that contains all applications and their associated impacts for each measure of effectiveness or benefit category.

If the user opts to estimate benefits for multiple V2I applications, the impacts for the applications will need to be combined into a single factor. The tool provides multiple methods for combining these impacts from which users can choose:

* + - Minimum impact of the selected applications;
    - Maximum impact of the selected applications;
    - Average impact of the selected applications;
    - Product of the impacts of the selected applications (example: 10% reduction and 20% reduction would yield 0.90 x 0.80 = 0.72 benefits).
* Step Two – Determining V2I-equipped vehicle fleet penetration rate: The tool provides four sets of vehicle fleet penetration rates – DSRC, DSRC-squared, cell phone, and 100 percent. The DSRC-squared rate is obtained from the National Highway Traffic Safety Administration (NHTSA) vehicle-to-vehicle (V2V) readiness report,[[4]](#footnote-4) where it represents the V2V communication equipment deployment in new vehicles. This penetration rate can also be applied in the case of V2I applications involving multiple vehicles, since the communication equipment needed will most likely be the same. The DSRC penetration rate is the square root of this rate and is used for applications that require DSRC in just a single vehicle. The cell phone penetration rate is used for V2I applications requiring cell phone technology. The tool uses a default cell phone penetration rate that is the same as DSRC, but the user can change this rate. The 100-percent penetration rate is used for applications that involve commercial or transit fleets, where communication equipment can be expected to be deployed at the same time as roadside infrastructure.
* Step Three – Determining the efficacy adjustment factor: The benefits realized from the deployment of a V2I application depend largely on the level of technology penetration. For any given application and V2I-equipped vehicle fleet penetration rate, the tool looks up a default efficacy adjustment factor which reduces benefits in the initial stages when the V2I-equipped vehicle fleet penetration rate is low.

Efficacy adjustment factors are drawn from an imbedded database that contains all V2I applications and the corresponding efficacy adjustment for each V2I-equipped vehicle fleet penetration rate. No literature could be found on efficacy adjustment factors, so the default values in the tool are based on engineering judgment. The database is designed as a flat file to facilitate the addition of factors as deployments expand and new information becomes available. Future research should document efficacy adjustment factors.

* Step Four – Calculating the adjusted V2I application impact: The adjusted impact is calculated by multiplying the steady state V2I application impact by the V2I-equipped vehicle fleet penetration rate and the efficacy adjustment factor for the application.

For each benefit category, the tool includes structure and logic (S&L) diagrams that describe the inputs, cause-and-effect relationships, and outputs for the sketch-planning tool. An S&L diagram illustrates how a metric is estimated. It is the graphical representation of an equation, where each box is a variable or parameter (e.g., input, model coefficient, intermediate output or final output) and links between boxes are operations (e.g., add, multiply or divide). Figure 5 provides an example of an S&L diagram for the estimation of safety benefits in the steady state case.

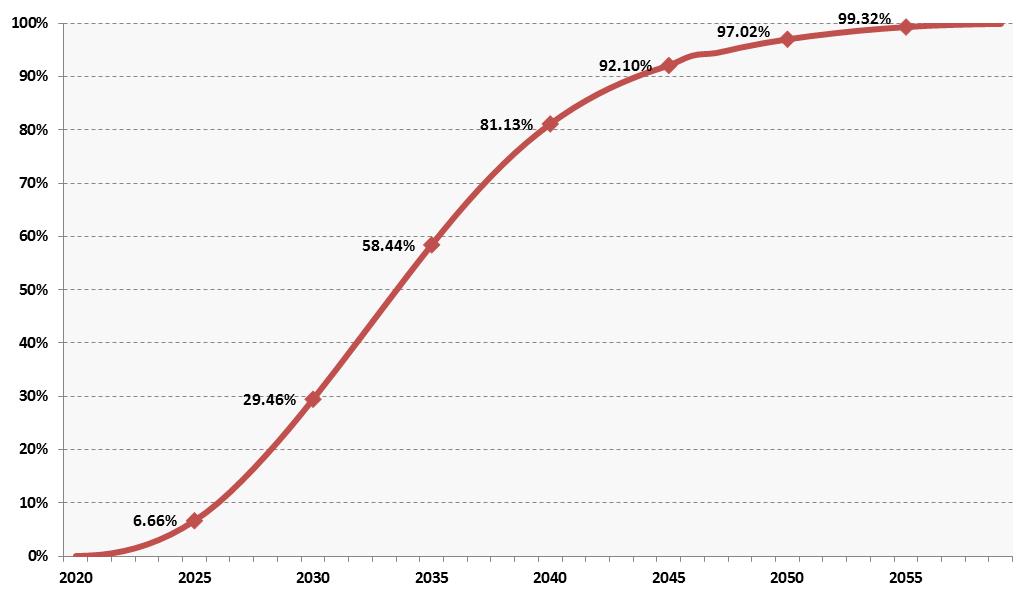
Figure 5: Example of Structure and Logic Diagram, Safety Benefits – Steady State



##### Vehicle V2I-Equipped Fleet Penetration Rate and Efficacy Adjustment

As noted above, VBET incorporates four sets of vehicle fleet penetration rates – DSRC, DSRC-squared, cell phone, and 100 percent. Figure 6 shows then estimated V2V communication equipment deployment rates used in the NHTSA study that is the basis for the DSRC and DSRC-squared penetration rates.

Figure 6: Example of Passenger Vehicle Fleet Communication Rate, 2020-2059



Source: National Highway Transportation Safety Administration

To incorporate the impact of the appropriate penetration rate, the tool looks up an efficacy adjustment factor which reduces benefits in the initial stages when the V2I-equipped vehicle fleet penetration rate is low. Efficacy adjustment factors are drawn from an imbedded database designed as a flat file to facilitate the addition of factors as deployments expand and new information becomes available.

The adjusted impact is calculated by multiplying the steady state V2I application impact by the V2I-equipped vehicle fleet penetration rate and the efficacy adjustment factor for the application.

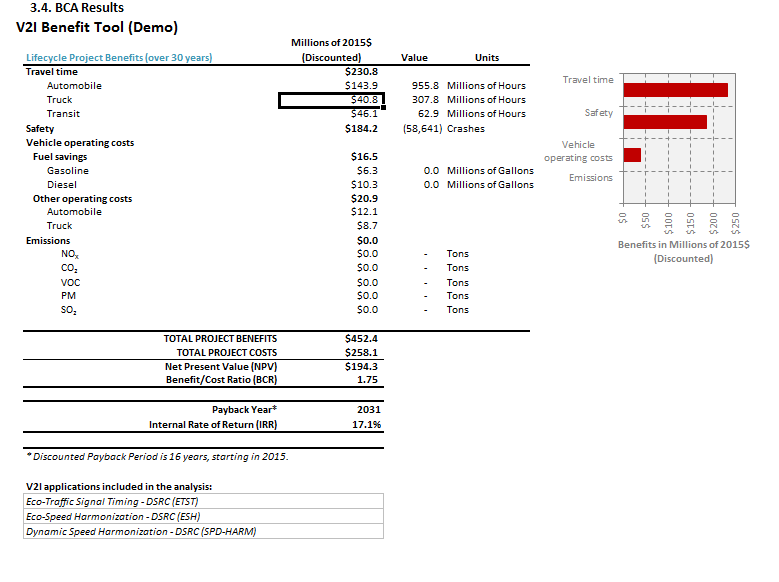
##### Benefit-Cost Analysis Output

The tool produces standard BCA summary metrics including:

* Net present value (NPV);
* Benefit-cost ratio (B/C);
* Payback period.

Results are presented in a summary table of benefits and cost by categories as well as by potential beneficiaries from the V2I application(s). Figure 7 shows an example of a BCA summary result table.

Figure 7: Example of Benefit-Cost Analysis Summary Results



###### Conduct Economic Impact Analysis

In addition to conducting a BCA, which compares the cost and benefits to society as a whole, the user can select to examine economic impacts, which are traditionally examined in local or regional terms. These are often the re-expression of direct transportation benefits with the exception of some wider economic benefits (e.g., agglomeration economies, job creation in areas of high structural unemployment or change in output due to increased competition), as well as transfers of revenue or “surplus” into the study area.

##### Impacts to Be Estimated

The tool estimates the long-term impacts resulting from reduced transportation business costs. These are economic impacts only from changes in business transportation savings and do not capture business attraction effects or effects from changes in technology. However, the tool will provide data that can be used as inputs in external economic development tools that measure these effects.

The tool estimates the impacts of changes in business transportation cost on:

* Employment;
* Income; and
* Gross regional product;

##### How Impacts Are Estimated

The tool includes a set of economic multipliers that describe the relationship between direct and indirect impacts. These multipliers indicate the overall change in economic activity resulting from successive rounds of spending and re-spending and, therefore, capture the full impacts of changes in business transportation cost in the local economy on both the business side and the household side.

The tool includes default multipliers from the Transportation Satellite Accounts (TSA) from the Bureau of Transportation Statistics. Users may use IMPLAN or other source for more precise estimates of local or regional multipliers (note that there are fees associated with accessing these multipliers).

The tool uses TSA’s direct requirement coefficients (Direct Use of Transportation per Dollar of Industry Output) to estimate the use of transportation services by industry based on the output of that industry in the study area. The use of transportation services by industry is then used to distribute the estimate of total freight transportation cost savings (calculated in the BCA module) across industries. As an example, if freight transportation costs are reduced by 100 overall in the study area and the Construction industry directly uses 5 percent of total transportation services, transportation costs in Construction are reduced by 5 percent. This is expressed as a percent change in production costs in the industry, using Output as a proxy for production costs. The Elasticity of Output with respect to (w.r.t.) Production Costs is applied to that percent to derive a percent change in Output. This provides an estimate of the direct change in Output, by industry, attributable to the initiative evaluated in the BCA. As a default, the Elasticity of Output w.r.t. Production Costs is set to -1.0 in all industries. This is the elasticity of output in one industry with respect to changes in production costs (and implicitly prices) in that industry. The TSA Output Multipliers (last row of the Total Requirements table) are then applied to the direct changes in Output, to derive estimates of total output impacts (direct and indirect) by industry.

Figure 8 presents a structure and logic diagram for the estimation of economic impacts from changes in transportation costs, using the national multipliers from USDOT’s Bureau of Transportation Statistics (BTS) and the U.S. Department of Commerce’s Bureau of Economic Analysis (BEA) Transportation Satellite Accounts (TSAs), developed to supplement national Input-Output (I-O) accounts with better estimate the impact of transportation services on the US Economy.[[5]](#footnote-5)

Figure 8: Structure and Logic Diagram for Estimation of Economic Impact



##### Economic Impact Analysis Output

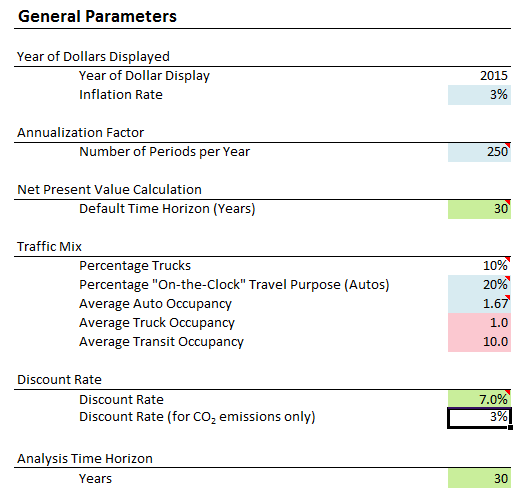
The tool presents the estimated impacts of a V2I application in terms of “total impact” (expressed in units such as dollars and jobs) and “unit impact” (calculated as the ratio of the total impacts to the baseline output). The total impacts may be used to indicate the size of the impact on the local economy. In contrast, the unit impacts may be used to indicate the rate-of-return of the V2I investment on the local economy.

###### Parameters

The tool includes a number of default parameters and economic values, such as the value of a statistical life and the real growth in value of time. The default values are based on current USDOT guidelines, including TIGER grant guidelines, TOPS-BC, and the CV literature. Users have the option of conducing BCA and EIAs using default values or modifying any or all of these defaults. This allows for flexibility to adjust for any unique circumstances in a particular area and also to incorporate any new V2I or other CV data.

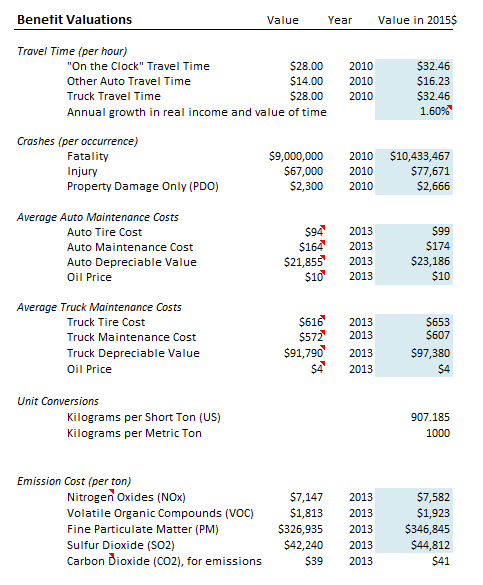
In both Simple and Advanced mode, users can access the parameters page of model if they wish to make any adjustments to the parameters. Table 14 and Table 15 provide examples of parameter values to be incorporated in the tool. Source information is keyed to the values for user review.

Table 14: Examples of General Parameters in Tool



*Note: Red triangles indicate a note to the user.*

Table 15: Examples of Benefit Valuation Parameters in Tool



*Note: Red triangles indicate a note to the user.*

###### Addressing Uncertainty in Inputs

Incorporating uncertainty into the economic analysis is critical in the context of a new set of technologies, such as V2I. Unlike many of other operational strategies (including those in TOPS-BC), V2I technologies have limited empirical evidence on which to base benefit estimates. Incorporating a formalized risk analysis with Monte Carol simulations was explored for VBET, but ultimately not included due to the relative lack of data on impacts and benefits to-date on V2I applications.

Currently, users can vary individual inputs in VBET and compare the results as a sensitivity analysis or explore the difference in results when electing how to combine the impacts of implementing multiple applications (e.g., minimum impact of the selected applications, maximum impact of the selected applications, and average impact of the selected applications) as discussed in ‘Benefits Estimation’ on page 54, above.

### Using Capability 4: Get Help

The fourth key capability of the tool serves as a reference guide and includes:

* An overview of the tool and what it does;
* Step-by-step instructions on how to use the tool.

# 

# Conducting Economic Analysis for V2I Applications

This section reviews the analysis approaches covered previously and summarizes where they have been applied, based on existing studies and syntheses of existing state practices. It also reviews tools currently available for state, local and regional entities to use for estimating potential impacts of V2I technology (and most of which have been address in previous sections of the document).

**Summary**

* States have been incorporating economic analysis into planning for transportation for some time, including guidelines for assessing impacts on economic development and on productivity.
* There are several publically available tools in addition to VBET that can be used by planners for assessing economic impacts (e.g., TOPS-BC, EconWorks, Cal-B/C).
* Users preferring to conduct a BCA outside VBET or other available tools can follow the steps outlined in this section.

This section does provide primary research. Instead, it reviews current literature on the subject of state practices for economic impact analysis. There is a wide variety in the methods and tools used to derive the costs and benefits associated with various projects and the ideology behind the ranking system used.

## Overview of State Practices for Economic Analysis of Transportation Projects

There is no single approach for assessing the impacts of transportation projects required by the Federal government for state and local governments. Rather, guidelines and requirements are specific to individual programs or regulations (such as the types of socio-economic statistics to review for NEPA and the BCA requirements for a TIGER application). States, local and regional public entities are left to determine which of the commonly accepted practices or available tools meet their needs. Nevertheless, USDOT, AASHTO, and TRB do offer guidelines and tools, many of which are reviewed above in Overview of Economic Analysis Approaches for Operations (see Chapter starting on page 8). Additionally, there are no regular surveys or reviews of state practices.

The best summaries of current practices are presented in two NCHRP documents that discuss how states are measuring economic impacts and assessing transportation projects.

### NCHRP 08-36-61 Monetary Valuation per Dollar of Investment in Different Performance Measures

The *Monetary Valuation per Dollar of Investment in Different Performance Measures* document goes through several case studies which identifies monetization performance measures and analysis techniques used by various state agencies. This overview includes analysis used for economic development impacts. The agencies include DOTs for the states of Florida, Montana and Indiana as well as the Appalachian Regional Commission.

#### Appalachian Regional Commission (ARC)

Established in 1965, ARC was formed to address above average poverty levels and lower quality of life in the region. They were to accomplish this through primarily focusing on economic development issues such as increasing job opportunities, strengthening the labor force within the region, developing and improving regional infrastructure and creating a highway system to increase inter-connectivity within the region and outside the region.

A 3,090 mile highway known as the Appalachian Development Highway System (ADHS) was planned with 2,632.5 of the miles completed or under construction by September 2005. Both predictive and evaluative analyses were included as part of the economic performance analysis of the ADHS using socio-economic trend analysis, EIA, BCA and economic and transportation modeling. These models usually include sources such as transportation and economic databases as well as business and public sector interviews. The tools used included the Highway Performance Monitoring System (HPMS) and the Highway Economic Requirements System (HERS) to calculate travel time savings and translate them into a monetary value. This was later used in the REMI regional economic forecasting model to measure the economic impacts of the highway which included jobs created, value added as well as changes to the wage rate and population in the region.

ARC also looked into the benefits of expanding intermodal facilities throughout the region. This analysis identified how projected increases in freight flows within the region could create bottlenecks which would be alleviated through investments into intermodal facilities and how these facilities could reduce the cost of doing business in the area. It went on to estimate how this could lead to travel efficiencies, job growth, larger Gross Regional Product (GRP), and more personal disposable income.

The models used by ARC often include public cost per job created, ratio of private investment to public investment and personal income created per public dollar spent. These measures help to better understand the economic impacts of the infrastructure projects ARC undertakes.

#### The Florida Department of Transportation (FDOT)

FDOT is considered one of the leaders regarding their focus on performance measures. They publish reports analyzing how well they are meeting their agency objectives several times a year. These objectives have included highway systems focusing on economic development and the creation of a Strategic Investment Tool (SIT Tool) which covers highway, rail, seaports, airports and transit.

Benefits measured in much of FDOT’s analyses include increases to Florida residents, employment changes and changes to Gross State Product (GSP). They also analyze changes in travel time, vehicle-operating costs and safety costs through use of HERS and the National Bridge Investment Analysis (NBIAS). This is then translated into a reduced cost of doing business in Florida while also measuring other business related impacts such as productivity benefits. The SIT Tool also includes a BCA to determine economic competitiveness of projects in order to choose the most beneficial projects to invest in. A mix of data sources and interviews were used in order to collect the data needed to input into a REMI economic simulation model which then output the expansion and attraction of firms due to reduced cost of doing business in the state. The Maritime Administration (MARAD) economic impact toolkit was used to help determine the economic benefits of increased seaport capacity.

#### Montana Department of Transportation (MDT)

MDT’s TranPlan21 statewide multimodal plan includes a major economic development element. Transportation performance measures used by the MDT include enhancement of mobility, cost effectiveness of transportation, change in amount of accidents and implementation of economic objectives.

The Highway Economic Analysis Tool (HEAT) developed for MDT is used to assess and monetize economic development benefits associated with transportation projects (limited to highway). Three goals of assessing the benefits were to identify which transportation investments would benefit which industries, provide an analytical toolbox that allowed for “economic development” impact evaluation (generally defined the same as economic impact assessment) and quantifying the economic impacts of transportation improvements. HEAT contains traditional benefit metrics such as travel time savings and reduction in operating costs, economic development impacts such as GSP and total benefits that are used in a BCA.

While HEAT estimates economic impacts, it does not account for environmental, safety and social benefits. The monetized data are used mostly for internal analysis within MDT. HEAT is calibrated specifically for Montana and is not readily transferable to other states.

#### Indiana Department of Transportation (INDOT)

The Major Corridor Investment Benefits Analysis System (MCIBAS) is a prelude to MDT’s HEAT. It estimates the benefits gained by the state’s businesses through economic impacts using a REMI model. Economic impacts are estimated in in terms of business cost savings (using a BCA model) and business attraction, which is manually estimated outside the model. Much like HEAT, MCIBAS is limited to highway projects. It can be used to evaluate transportation programs, corridor plans and potential projects along with their alternatives. MCIBAS follows a standard BCA framework.

### NCHRP 02-24: Economic Productivity and Transportation Investment Priorities

This report was intended to design a methodology and guide to aid state DOTs and MPOs in assessing economic productivity gains and analyzing transportation investments. It presents a general framework on the use of productivity impact metrics and how they can be beneficial to the user. This document distinguishes between economic impact, economic benefit and productivity. It states that the economic impact of a transportation investment is the growth of economic activity which reflects productivity gains. An economic benefit represents social welfare gain plus productivity gain. The productivity impact shows gains in efficiency by businesses.

The NCHRP 02-24 Task 1 Literature Review, Stakeholder Perspective and Framework Outline continues the discussion by showing current practices at the state level. Interest in economic development spans three functions across states, to aid in statewide long range plans, alternatives for major corridor studies and to help rank and select alternative projects. States also differ on their policies concerning economic analysis. Some make the analysis mandatory while for other states it is completely voluntary.

The report’s authors interviewed 23 public and private agencies, representatives of state DOTs and MPOs regarding the consideration of productivity effects and economic impacts when prioritizing and selecting projects. They found that use of economic analysis varies from required (for some or all or types of projects) to voluntary, and that some agencies considered potential impacts to business cost competitiveness. The perspectives gathered in the interviews are summarized below.

#### Long-Range Statewide Transportation Plans

States prepare long range transportation plans. Often, these plans are drawn from and compare studies looking at differing amounts of investment options. The studies usually take into account benefits such as travel delay, can include job and GDP growth, and often fall into one of two categories – multi-modal vision plans and statewide investment policy studies. Multi-modal vision plans can cover a 5-year to 30-year period in which a transportation investment strategy is put into place. The plans are constructed to compare the job growth from current spending to growth from other spending amounts. Examples of states that have used this type of study include the Maine DOT and Virginia DOT both of which analyzed highway and rail connectivity between cities. Statewide investment policy studies demonstrate the importance of continued investment in transportation to the business community and general public through the use of economic impact models. Some states that have used these types of studies include the Oregon DOT, Kansas DOT and Michigan DOT.

## Existing Application of Economic Analysis to V2I

As CV is still a relatively young field, there is little research literature with observed data available to support economic analyses. The previous section on **Connected Vehicle Benefit and BCA Studies,** beginning on page 43, discusses the few currently available.

In August 2015, Volpe released its *Benefits Estimation Framework for Automated Vehicle Operations.[[6]](#footnote-6)* The framework describes the foundation for integrated sub-models to support the analysis of automated vehicles to be developed during the next phase of their work in order (from page 10):

• Safety: Safety modeling primarily deals with the behavior of the driver/vehicle/automation system in the seconds leading up to a potential crash. Thus, safety modeling tends to be performed at an extremely fine-grained level of spatial and temporal resolution with the results being rolled up into national benefits.

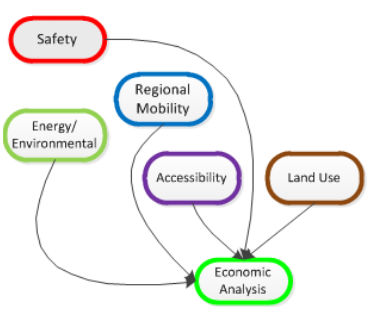
• Vehicle and Regional Mobility: Vehicle mobility deals with car following, gap acceptance, and other detailed aspects of vehicle performance. Regional mobility is at a less fine-grained spatial and temporal resolution, and deals with the performance of a highway corridor, an intersection, or a region.

• Energy / Environmental: A detailed driving cycle (i.e., idle time, acceleration, cruise, and deceleration) that comes from the mobility modeling is fed into a model that calculates energy consumption and emissions.

• Transportation System Usage: Travelers change their travel patterns in response to changes in mobility (for example, if a road becomes less congested, it may receive more use). This part of the framework captures the traveler responses to changes in mobility and accessibility. As such, it drives most of the feedback. In the longer term, car ownership and shared ride options may change.

Figure : Volpe Framework – Relationship between the Economic Analysis Sub Model and the Rest of the Framework

• Accessibility: Accessibility measures the ability of people to reach desired destinations.

• Land Use: Land use addresses the density and mix of development in a particular region

• Economic Analysis: Many of the other benefits, including reduced cost of crashes and congestion and improved access to jobs, lead to economic benefits

The economic analysis will focus on the likely long-term macroeconomic impacts of automation. It is planned as a follow-on to the other modeling efforts. The Volpe *Framework* acknowledges that “existing research in this area is fairly limited”.

## Additional Tools for Transportation Benefits Analysis

In addition to VBET, the tool developed to accompany this desk reference, there are several tools to help state, local, and regional decision-makers, although the tools may not specific to V2I. Several of the best known of these tools are briefly discussed. All easily are available for little to no charge.

### TOPS-BC

The Tool for Operations Benefit Cost Analysis (TOPS-BC) is a spreadsheet-based decision support tool developed by the FHWA Office of Operations. It supports the application of benefit-cost analysis (BCA) for a wide range of Transportation System Management and Operations (TSM&O) strategies. The tool can screen multiple TSM&O strategies and provide "order of magnitude" BCA estimates. The intended audience for TOPS-BC is system operators and transportation practitioners who need to conduct BCA for a wide range of TSM&O strategies and make decisions for their deployment.

TOPS-BC provides four key capabilities:

* Investigate Impacts – The ability to investigate the expected range of impacts associated with previous deployments and analyze many TSM&O strategies;
* Research Methods – A screening mechanism to help identify appropriate tools and methodologies for conducting a B/C analysis based on analysis needs;
* Estimate Costs – A framework and default cost data to estimate the life-cycle costs (including capital, replacement, and continuing O&M costs) of various TSM&O strategies; and
* Estimate Benefits – A framework and suggested impact values for conducting simple B/C analyses for selected TSM&O strategies.

In addition to these capabilities, TOPS-BC also is intended to serve as a repository of relevant parameters and values appropriate for use in benefit-cost analyses and based on observed impacts from transportation projects. Although the tool provides BCA estimates based on default parameters, users can use local data or data derived from other models.

A stand-alone User’s Manual is available to guide interested practitioners in the proper set up and application of the TOPS-BC spreadsheet tool.

One noted benefit of TOPS-BC is that it acknowledges the synergistic effects of combined strategies and considers the impacts of physical, non-physical, and supporting strategies when assessing projects. TOPS-BC is designed to analyze performance on a single corridor for most of the strategies considered, and not as well suited to regional analyses.

The sketch planning capabilities within TOPS-BC are generally applicable for analyses at the visioning and screening stage and partly at the long-range planning for screening and estimating the order of magnitude of benefits. The more complex and detailed analysis required for program and project development may warrant the application of a more robust analysis tool.

A critical limitation of TOPS-BC, of course, is that its data is all drawn from more traditional transportation construction projects and does not explicitly address some of the critical issues for CV implementation and assessing its impacts including: the net interactive impacts of various components which would be implemented under an applications (as per AASHTO Footprint); a ramp-up of benefits reflecting changes in penetration rates of the CV equipment in vehicles and geographically necessary to take advantage of the applications, among other impacts. Another limitation is that TOPS-BC is designed to analyze performance on a single corridor for most of the strategies considered, and not as well suited to regional analyses.

### ECONWORKS

EconWorks Case Studies can be a potentially useful tool for estimating economic development impacts. It is a searchable database of 105 transportation projects with data that can be used as proxies to estimate the potential impact of CV applications, including information on employment, income, and tax revenue. As noted above, using EconWorks information would be as part of a “benefit-transfer” approach that can be helpful in early-stage assessments.

EconWorks Case Studies have been integrated into the “EconWorks” suite of tools (<https://planningtools.transportation.org/13/econworks.html>) for assessing the Wider Economic Benefits (W.E.B.) of transportation investments. The EconWorks Economic Analysis Tools (C03 and C11) are designed to help transportation professionals make more comprehensive and realistic assessments of the economic development impacts of transportation projects. These tools help estimate which transportation improvements will support economic vitality by allowing decision makers to gauge the potential increases in jobs and output, and by providing estimates of economic benefits in the areas of travel time reliability, access to labor and goods markets, and intermodal connectivity.

* Case Study Search: a library of case studies, searchable by project attributes, to demonstrate the economic impacts of transportation investments. Available information includes descriptions of project features and pre/post data about impacts on the local or regional economy.
* Assess My Project: A web-based tool that estimates the economic impact of potential projects based on parameters defined by users.
* Wider Economic Benefits Analysis Tools: Downloadable spreadsheets useful for assessing the wider economic benefits from transportation projects.
  + The Accessibility Tool is designed to quantify the benefits and impacts of a project to the labor and buyer-supplier markets.
  + The Reliability Tool obtains the benefits of projects that improve travel time reliability.
  + The Connectivity Tool monetizes the benefits and impacts of improved intermodal connectivity.
  + The Accounting Framework provides a place to assemble the results of the accessibility, reliability and connectivity tools alongside more traditional benefits categories like safety, travel time savings and vehicle operating cost savings.

EconWorks data may be useful for helping to estimate the potential scope or magnitude of CV impacts on economic development in concert with direct impacts that are estimated under a BCA framework. Using EconWorks without a BCA framework may lead to results which are far too speculative and which miss the opportunity to be aligned with more robust estimates of direct impacts.

### Cal-B/C

Cal-B/C is an MS Excel spreadsheet-based tool used by the California Department of Transportation to analyze proposed projects for investment purposes. The tool can prepare analysis for highway, transit and passenger rail projects and covers capacity expansion, transportation management systems and operational improvements. The results calculated from the analysis includes life-cycle costs, net present values, benefit-cost ratios, internal rates of return, payback periods, annual benefits and life-cycle benefits.

The model covers four categories of benefits derived from transportation projects including:

* Travel time savings;
* Vehicle operating cost savings;
* Crash cost savings;
* Emission reductions.

Three performance measures are also included:

* Person-hours of time saved;
* Additional CO₂ emissions saved in tonnage;
* Additional CO₂ emissions saved in dollars.

Benefits are calculated for both peak and non-peak periods to account for the difference in congested and free flow traffic conditions and characteristics. The results are displayed in constant dollars with final investment measures as well as annualized and lifecycle benefits.

The inputs needed by the model to complete the analysis (to be provided by the user) include annual person-trips for transit projects and annual average daily traffic for highway projects. Free-flow speeds, transit vehicle miles, crash data and costs are entered on a year-by-year basis as needed.

### Adjustments to Existing Models for V2I Analysis

The above discussed tools were developed for more traditional transportation investments. As noted above (in “What Makes Connected Vehicles Different from Other ITS Investments, and the Implications for Estimating Benefits,” on page 6) there are a few characteristics of V2I technology which make estimating the benefits of those applications more challenging.

* Because the full benefits of V2I applications cannot be realized until a certain portion of vehicles, and for some applications, roadside facilities, are equipped with enabling technology, benefits may not be realized immediately.

Therefore, users should take care to consider addressing this issue, such as by adding a ramp-up factor for benefits.

* Many V2I applications and components under development can be deployed in ways that lead to lower aggregate implementation costs. For instance, one application may be able to make use of back office telecommunications equipment being put into place for another application. In such instances, a coordinated deployment would incur lower costs than deployment of the same applications separately.

If planning for implementing multiple components or applications, users should consider factors that incorporate some cost efficiencies of coordinated deployments and adjust cost accordingly, otherwise they risk overestimating costs.

* In addition, there are many applications currently under development and deployment that can be deployed together in ways that may create efficiencies (or inefficiencies) for secondary costs such as network security infrastructure and operations monitoring. These operating efficiencies can lead to lowering aggregate operating costs, which is a benefit to the operating agencies

Therefore, users evaluating plans for the implementation of multiple components or applications should seek to incorporate factors reflecting potential system-wide operations and maintenance efficiencies.

As the field is still very young, there are no robust estimates of what these adjustment factors should be. Therefore users may need to seek guidance from other staff, internal offices, or experts regarding appropriate values to use.

## How to Conduct Economic Analysis for V2I Applications

The easiest way to conduct an economic analysis for a V2I application is to use VBET or one of the tools discussed in the subsection Additional Tools for Transportation Benefits Analysis, beginning on page 69. However, one must be careful to consider the adjustments discussed on page 72.

***How do I use the V2I Benefits Estimation tool and where can I get it?***

* *See Chapter V “V2I Benefits Estimation Tool” starting on page 56*
* *Use the V2I Benefits Estimation tool for estimating the local, regional, and state-wide economic development benefits of connected vehicle to infrastructure deployments developed with the desk reference, which is available on the FHWA website*

Some sophisticated software users may prefer to build their own customized estimation from scratch, using software such as Microsoft’s Excel. FHWA’s *Economic Analysis Primer* and FHWA’s *Operations Benefit/Cost Analysis Desk Reference* can be used to help guide the construction of such customized analyses.

Whether building a model from scratch or using an existing tool, before beginning any economic analysis for any V2I applications, users should being by asking themselves questions they are trying to answer with the analysis. If the main purpose of the analysis is to put a dollar value on the likely direct impacts of a project, to assess whether the costs of a project are outweighed by the value of the benefits it generates, then a BCA analysis is the best methodology. A BCA puts a dollar value on the costs and impacts – both negative and positive. Note that beneficiaries may or may not be only those from nearby communities.

If instead, the primary focus is the impacts on the economy of the dollar spent implementing the transportation investment, than and EIA is the preferred approach. If the goal is to estimate and potential long-term changes in local economic activity, including growth of new residential, commercial and/or industrial buildings then one of the approaches to estimating economic development discussed in section Appendix: Other Approaches to Modeling Economic Development (page 84) may be appropriate.

Different audiences may be partial to different approaches and their outputs. Some may favor analyses which focus on local jobs, taxes, and other economic impacts that directly affect communities, while others are more concerned with broader impacts.

## Conducting Economics Analysis of V2I Applications Outside of VBET

For users who may wish to conduct a BCA outside VBET, the following summarizes the critical steps to take and issues to consider in such an analysis.

***Are there any reports with more detailed help on building a BCA model from scratch?***

* *See FHWA’s Economic Analysis Primer, 2003; FHWA’s Operations Benefit/Cost Analysis Desk Reference [*[*http://www.ops.fhwa.dot.gov/publications/fhwahop13004/fhwahop13004.pdf*](http://www.ops.fhwa.dot.gov/publications/fhwahop13004/fhwahop13004.pdf)*]; or NCHRP’s Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners [*[*http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)\_FR.pdf*](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)_FR.pdf)*].*
* *See Chapter 12 in Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners, NCHRP Project 8-36, 2011 [*[*http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)\_FR.pdf*](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)_FR.pdf)*]*

How to Conduct a Benefit-Cost Analysis

1. **Identify application(s); if more than one, identify overlaps in cost/impacts**

Begin by identifying the applications for analysis, including clarifying specifications for implementation. The users should pay particular attention to:

* Where the application will be implemented, including over what roadway equipped vehicles will be making use of the applications capabilities;
* What vehicles will be using the applications (i.e., a public agency’s fleet, private vehicles which contain an appropriate on-board unit, etc.);
* Any other necessary equipment or implementation issues, such as additional back office processing capacity, etc.

***Where do I check for the latest updates from FHWA and AASHTO on CV and V2I applications?***

* *Go to:*
* [*http://www.its.dot.gov/research.htm*](http://www.its.dot.gov/research.htm)
* <http://ops.fhwa.dot.gov/travelinfo/infostructure/aboutinfo.htm>
* [*http://stsmo.transportation.org/Pages/Connected-Vehicles.aspx*](http://stsmo.transportation.org/Pages/Connected-Vehicles.aspx)

A discussion with local staff that will be responsible for managing the application and its implementation will likely be helpful, as well as checking FHWA’s and AASHTO’s webpages on connected vehicles (see sidebar).

If there are multiple applications to be analyzed, determine if they will share any equipment or other elements that would affect implementation costs and/or impacts. For instance: would they make use of the same vehicle OBUs, make use of the same or some of the same backend technology, roadway equipment, etc.

1. **Identify constraints and specify assumptions**
   1. Fleet penetration rates;
   2. Other potential parameters such as phasing of other critical equipment over multiple., and different, years

Since the impact of connective vehicle technology is dependent on the existence of specialized equipment, among other issues (see discussion on What Makes Connected Vehicles Different from Other ITS Investments, and the Implications for Estimating Benefits, page 6 for a short review of these issues), specification of those variables will be critical in the BCA. The discussion of an assumed vehicle penetration rate (page 53) in the Chapter V2I Benefits Estimation Tool can offer some guidance.

1. **Define the baseline (“no-build”) and improvement (“build”) scenarios**

A crucial step in any economic analysis of a transportation project is defining the baseline against which impacts of an improvement are measured. Sometimes termed a base case, or no build (in contrast to the build) scenario this baseline is an estimation of what is reasonably expected to occur without the transportation improvement. The baseline usually includes estimates of the expected levels and changes in population and traffic as well as other factors critical to individual projects (e.g., overall expected growth in exports when assessing major freight corridors near international ports).

Then, the improvement’s scenario needs to be defined, in which the applications to implemented are clarified. This step is very closely aligned with step 1, above, in which the applications to be analyzed are specified.

1. **Determine the appropriate timeframe**

***Where can I find additional guidance on how to estimate changes in vehicle operating costs?***

* *See* ***chapter 4*** *in* *Guidebook for Assessing the Social and Economic Effects of Transportation Projects, NCHRP report 456, 2001 [*[*http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp\_rpt\_456-a.pdf]*](http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_456-a.pdf%5d)*.*

Laying out the appropriate timeframe is critical. Infrastructure investments are very large, can be very costly to implement as well as maintain, and have the capacity to impact many people for a long time. Given the scale of the costs and potential impacts involved, selecting an appropriate timeframe is critical.

Determine how many years are needed to put the application in place; if there are going to be multiple applications, then consider if they will be implemented at the same time, or not (such as a staggered implementation, with some put into place only after others are operational, or several start at the same time but take different amount of time to complete, etc.).

The US Department of Transportation suggests 20 years as a minimum number of years to adequately analyze the impact of transportation projects requesting TIGER grant funds. But investments in V2I applications may need a longer timeframe since the benefits of these investments are at least partly dependent on the adoption of necessary equipment by commercial and non-commercial vehicles and of implementation across local, regional, and national transportation networks. Since this field is still relatively young, and the necessary equipment is not yet likely in place, the V2I Benefits Estimation Tool uses a 30-year period of analysis. Users estimating impacts independently should carefully consider what time frame would be most appropriate to their situation.

1. **Configuring the BCA Local Conditions**

The TOPS-BC Desk Reference specifically discusses how to customize economic analyses for local conditions, an issue which is worth including as a separate step here. Since to date there is very little literature on observed impacts of V2I technology in the field, the few current data points may not apply well to all local situations. If drawing on the literature from the field at large to estimate impacts and not on data which was developed locally, planners estimating impacts and benefits may find that they need to adjust impacts to reflect their difference local conditions, such as different mix of vehicle types, difference geography and weather patterns, etc. This will necessarily be in inexact exercise, but with consultation with local experts should lead to better final estimates.

1. **Estimating the Lifecycle Costs**

***Where can I get general cost estimates for many V2I applications?***

* *AASHTO Near-Term Life-Cycle Costs for V2I Application Deployment Cost Estimation Tool* on the FHWA website
* *CO-PILOT [*[*https://co-pilot.noblis.org/  
  CVP\_CET/*](https://co-pilot.noblis.org/CVP_CET/)*]*

A good BCA incorporates a full range of costs, both costs to the implementing agency as well as any potential costs to users and/or the outside community (such as temporary increases in travel times due to construction/implementation). The lists below include common costs associated with transportation projects to be considered:

1. Agency Costs Implementation Costs

* Design and engineering
* Land acquisition (if needed)
* Construction

1. Agency Costs Maintenance and Operations Costs

* Preservation/Routine maintenance
* Annual operations

1. User Costs/Benefits Associated With Work Zones

* Delay
* Crashes
* Vehicle operating costs

1. User Costs/Benefits Associated With Facility Operations

* Travel time and delay
* Crashes
* Vehicle operating costs

1. Externalities (nonuser impacts, if applicable)

***Where can I find additional guidance on estimating changes in accidents, independently from the estimates on V2I applications impacts?***

* *See Chapter 3 in* *Guidebook for Assessing the Social and Economic Effects of Transportation Projects, NCHRP report 456, 2001 [*[*http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\_rpt\_456-b.pdf*](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_456-b.pdf)*.*
* Emissions;
* Noise;
* Other impacts.

Note that many V2I applications may have very few if any measurable user costs.

Alternately, costs for a V2I application can either be drawn from the AASHTO Near-Term Life-Cycle Costs for V2I Application Deployment Cost Estimation tool or FHWA’s CO-PILOT tool (see side bar).

1. **Estimating the Impacts**

The next step is to estimate the impact of these applications on transportation in the corridor. Note that impacts begin after construction/  
implementation begin and may not be full realized immediately (see steps 2 and 4 above). Traditionally, the impacts of a transportation project are measured as a change in travel times, speeds, crashes, the flow and number of vehicles traveling along a facility, and/or cargo through put.

***Where do I find recommend values to help me estimate the dollar value of my project’s impacts?***

* *See USDOT’s TIGER Benefit-Cost Analysis (BCA) Resource Guide –found at [*[*https://www.transportation.gov/sites/dot.gov/files/docs/Tiger\_Benefit-Cost\_Analysis\_%28BCA%29\_Resource\_Guide\_1.pdf*](https://www.transportation.gov/sites/dot.gov/files/docs/Tiger_Benefit-Cost_Analysis_%28BCA%29_Resource_Guide_1.pdf)*]*

Most findings on the impacts of V2I applications have focused on safety, with some research on travel time savings as well – the section on Connected Vehicle Benefit and BCA Studies, beginning on page 43, summarizes the findings to date. The findings on data regarding impacts are summarized in Table 6: Summary of V2I Benefits Descriptions from BCA Literature and Table 13: Summary of Quantified Impacts of V2I Literature, above. Users can draw from these tables to estimate annual impacts on safety, travel time, roadway capacity, and fuel savings (for vehicle operating cost savings).

The estimated crash and travel changes are applied against the baseline conditions (specified in step 2) in order arrive at estimated impacts for specific applications at a specific place (roadway, corridor, etc.) These estimates are applied annually for each of the years in the analysis.

1. **Valuing the Benefits**

***Where can I find additional guidance on how to estimate changes in travel time?***

* *See Chapter 2 in* *Guidebook for Assessing the Social and Economic Effects of Transportation Projects, NCHRP report 456, 2001 [*[*http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\_rpt\_456-b.pdf*](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_456-b.pdf)*]*

Once changes in crashes, travel time, capacity and/or other impacts are estimated for a BCA, then dollar values are put to each of these benefits so as to compare them against costs. The US Department of Transportation has collected a set of recommended values to use when valuing the impacts of transportation projects, prepared for its TIGER program. This listing includes standards values used in transportation economics for the value of a statistical life, accidents of varying severity, and for travel time by vehicle (truck, car) and trip purpose (work, non-work).

1. **Evaluate risks**

Because there is so much uncertainty underlying the 20 or 30 estimates of impacts needed for conducting a BCA on transportation projects, many recommend additional ‘risk analysis’ in which analysis is done on the uncertainty underlying key inputs (FHWA’s *Economic Analysis Primer* includes a short ‘Risk Analysis’ chapter). The two most common approaches are to perform: i) sensitivity analyses, and/or ii) a formalized probabilistic analysis; both are introduced below.

***Where do I find more information abut discounting values?***

* *FHWA’s Economic Analysis Primer, 2003;*
* *FHWA’s Operations Benefit/Cost Analysis Desk Reference [*[*http://www.ops.fhwa.dot.gov/publications/fhwahop13004/fhwahop13004.pdf*](http://www.ops.fhwa.dot.gov/publications/fhwahop13004/fhwahop13004.pdf%20) *]; or NCHRP’s Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners [http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)\_FR.pdf]*

Conducting a sensitivity analysis has traditionally been the method for evaluating the underlying uncertainty of estimates in a BCA. In a sensitivity analysis, a key input or inputs are varied one at a time and separately in order to better understand how variability in that one input affects the final result. This helps analysts and planners better assess how ‘robust’ or strong final results are with respect to the uncertainty of key inputs.

A formalized probabilistic analysis is a more sophisticated approach to incorporating risk into a BCA and entails incorporating an assessment of the uncertainty of multiple variables at the same time usually using specialized software. The most common approach is to conduct a Monte Carlo simulation, in which numbers for key inputs are randomly taken from a predefined range or values are run simultaneously through the BCA formulas several thousand times (commercial software is available to automate Monte Carlo modeling). The results are then arrayed to give a sense of the range of likely final results. When using these software programs, users apply ranges of values only to those inputs for which such values can be robustly estimated and which are likely to have a notable impact on final results or to be very likely to vary. Perhaps more importantly, users should be aware that at the time of publication, there was not adequate data for robust formalized probabilistic analyses using Monte Carlo simulations on CV technologies.

1. **Analyze and present results**

Once information on costs and the valuation of likely impacts is collected, it should be organized over the period chosen for analysis, followed by an estimation of aggregate costs and benefits. Costs and benefits in a BCA should be presented as discounted values, which are adjusted for a time value of money that reflects the default preference for having money sooner. Discounting is particularly valuable in helping to compare different investments, including those in transportation infrastructure, with different streams of costs and benefits. Many commonly used spreadsheet programs have functions to help discount future streams.

The most commonly used summary results from a BCA are:

* Net present value (NPV) – total benefits over the improvement’s expected life (or other period of analysis), discounted to the present less total costs over the improvement’s expected life (or other period of analysis), discounted to the present. If benefits are positive, then expected benefits are greater than expected costs.
* Benefit-cost ratio (BCR) – the present value of benefits divided by the present value of costs. A BCR can be presented as the return on a dollar of investment.

If an EIA is also conducted for the improvement, FHWA recommends that the EIA be presented as complementary to the BCA:

*BCA results show whether a project is worth the resources that will be invested in it from a total social welfare standpoint. EIA results are helpful in informing decision makers and the public about how and in what form the benefits and costs of the project will ultimately be distributed within the economy. (Economic Analysis Primer, page 34)*

***Where do I find help on preparing an EIA for my project?***

* *See FHWA’s Economic Analysis Primer, 2003; NCHRP’s Guidebook for Assessing the Social and Economic Effects of Transportation Projects [*[*http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp\_rpt\_456-a.pdf*](http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_456-a.pdf)*]; or NCHRP’s Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners [*[*http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)\_FR.pdf*](http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp08-36(101)_FR.pdf)*].*
* *See Chapter IV “V2I Benefits Estimation Tool” starting on page 49.*
* *Use the V2I Benefits Estimation tool for estimating the local, regional, and state-wide economic impacts of connected vehicle to infrastructure deployments developed with the desk reference*
* *Other available tools include:*
  + *IMPLAN (IMpact analysis for PLANning).* [*http://www.implan.com/*](http://www.implan.com/)
  + *Regional Economic Models, Inc. (REMI).* [*http://www.remi.com/*](http://www.remi.com/)
  + *Transportation Economic Development Impact System (TREDIS). www.tredis.com*

In addition, care should be taken so as not to present the BCA and EIA results as additive, since the two methods are measuring the same impacts in different ways.

How to Conduct an Economic Impact Analysis

There are many different approaches to conducting an economic impact analysis, although most fall into one of two categories: studies or surveys and computerized economic modeling. The first group includes:

* Business and expert interviews, and other surveys can be one of the easiest and most flexible approaches to high-level understanding of economic impacts.
* Case studies are examinations of similar, existing situations in which the impacts of investments are examined, via interviews and economic data, so as to gain a good qualitative understanding of the scope and scale of benefits and sometimes quantify those benefits. Analogies can be drawn from the existing situation to the planned improvement.
* When the focus is on the effects of investments on a particular industry, market studies can be conducted. In these analyses, the anticipated change in transportation costs is incorporated into estimates of supply and demand for that industry so as to estimate the resulting change in price and sales in that industry.

Regional models with input-output analysis are available to estimate the “multiplier” effects of additional spending due to the investment. These effects reflect money earned directly from the spending to implement an improvement and money generated from increases in local productivity. There are several available tools (see box above) that can be used to estimate economic impacts, such as jobs, earning, and tax revenue. NCHRP’s *Guidebook for Assessing the Social and Economic Effects of Transportation Projects* and NCHRP’s *Understanding How to Develop and Apply Economic Analyses: Guidance for Transportation Planners* provide detailed steps for conducting several of these types of analysis.

# Upcoming and Expected Research and Studies

## Upcoming Research

CV technologies, their deployment and data showing the effects of these technologies are still evolving, leaving much research to be done. Much of this work is being spearheaded by the USDOT.

**Summary**

* USDOT funded pilots and research programs are listed, with links for more information.
* Other resources are available, including AASHTO Footprint and Near Term Analysis

Due to the lack of deployment impeding further research in the area of CV technology, the USDOT is funding State Pilot Programs allowing CV technology to be implemented on a larger scale and at a quicker pace. The USDOT connected vehicle pilots program aims to create a safe, interoperable wireless communication network across vehicles, infrastructure and personal communication devices. This program is expected to bring CV research into a practical environment, enhancing operational capabilities and inducing innovation through partnerships across public and private entities. The data collected from this pilot program will prove invaluable to future research in the field. Data will be captured from multiple sources including the vehicles and mobile devices, across multiple transportation systems (freeways, parking facilities, transit). Phase 1 of the deployment program schedule includes New York City, Tampa Bay, and along parts of Interstate 80 in Wyoming. A second wave of CV Pilot Program Deployments was announced in September 2015.

Information regarding these studies can be found at the following links:

|  |  |
| --- | --- |
| **Research** | **Link** |
| Connected Vehicles Pilots Deployment Program | [http://www.its.dot.gov/pilots/](http://www.its.dot.gov/pilots/%20) http://www.its.dot.gov/pilots/index.htm |
| FHWA Connected Vehicle Pilot Deployment (CV Pilots) Program NYC | <http://www.its.dot.gov/pilots/pdf/02_CVPilots_NYC.pdf> |
| Wyoming DOT Connected Vehicle Pilot Deployment Program | <http://www.its.dot.gov/pilots/pdf/04_CVPilots_Wyoming.pdf> |
| Connected Vehicle Pilot Deployment Program Phase 1 Tampa | <http://www.its.dot.gov/pilots/pdf/03_CVPilots_Tampa.pdf> |
| Connected Vehicles Pilot Deployment Program Fact Sheet and Schedule | <http://www.its.dot.gov/factsheets/pdf/JPO_CVPilot_v3.pdf> |

In addition, AASHTO is building off its Footprint, (see discussion under “AASHTO Footprint Analysis,” beginning on page 27 for more details on the Footprint) with its Near Term Vehicle-to-Infrastructure (V2I) Transition Phasing and Analysis. This project is designed to better understand the initial (first five years) planning and implementation decisions for V2I applications at the state, local and regional levels. Life-cycle costs developed under this project can be used in VBET (see section “Using VBET,” above). Additional tools to facilitate prioritization were also developed. Additional information on AASHTO’s efforts can be found at: <http://stsmo.transportation.org/Pages/Connected-Vehicles.aspx>.

## Additional Resources

USDOT’s V2I safety research program has four main objectives:

* Develop a system that transfers information between vehicles and infrastructure.
* Create guidelines for the components and systems that allow the transfer of information to take place.
* Provide the tools and guidance needed by decision makers on deployment, operation and maintenance of V2I systems.
* Ensure appropriate privacy, security and system certification, interoperability, scalability, oversight and public acceptance strategies are in place and that the policies in effect are capable of creating a marketplace able to sustain the deployment of infrastructure components.

Similar to V2I Communications for Safety, V2V Communications for Safety is technology created as a way for safety data to transfer wirelessly. Unlike V2I Technology, however, V2V Technology transfers safety data between vehicles. The USDOT has set four main objectives for V2V safety research as well, which includes:

* Developing safety applications that address the most critical crash situations.
* Develop safety benefit estimations that aid in the assessment of NHTSA agency decisions.
* Work with industry in a way that allows the acceleration of safety benefits through use of the technology.
* Build, develop and test V2V communications technologies and standards.

Additional resources are available through the following links:

|  |  |
| --- | --- |
| **Technology** | **Link** |
| Connected Vehicles | [http://www.its.dot.gov/landing/cv.htm](http://www.its.dot.gov/landing/cv.htm%20) |
| Vehicle to Infrastructure Technology | [http://www.its.dot.gov/safety/v2i\_comm\_safety.htm](http://www.its.dot.gov/safety/v2i_comm_safety.htm%20) |
| Vehicle to Vehicle Technology | [http://www.its.dot.gov/safety/v2v\_comm\_safety.htm](http://www.its.dot.gov/safety/v2v_comm_safety.htm%20) |
| CO-PILOT | [https://co-pilot.noblis.org/CVP\_CET/](https://co-pilot.noblis.org/CVP_CET/%20) |

# Appendix: Other Approaches to Modeling Economic Development

Theory suggests a number of mechanisms by which transportation projects may improve the performance of an economy. They include:

* Increases in business output resulting from lower costs of production;
* Effects on labor market catchment areas and labor costs;
* Unlocking inaccessible sites for development;
* Expanding market reach and fostering competition;
* Reorganization of production, warehousing and distribution;
* Changes in land use, including business relocation/attraction; and
* Stimulation of inward investment.[[7]](#footnote-7)

As already noted, *how* transportation projects affect the economy is well understood, however under most circumstances, the magnitude of these changes and their cumulative effects on the economy cannot easily be estimated. One important reason for this is that there are no well-established theories to help predict how economic agents will respond to changes in travel conditions. This has been highlighted by many in the literature. Thus, Roger Vickerman observed:

*“There is no a priori relationship between transportation improvements and their consequences for the economy.”* House of Commons Transport Committee (2011), page Ev.142;

And, Ian Wallis of the New Zealand Transport Agency explained:

*“Economic theory offers no conclusive guidance regarding the (…) impact of transport investment on specific regional economies. Issues such as the ‘two-way road problem’, the need for supporting measures, well developed transport networks and economic displacement effects cloud the ultimate impacts of transport investment on economic development within a specified ‘target region’.”* Wallis (2009), page 11

As a result, predicting the economic consequences of transportation investments typically involves the use of highly structured simulation models. The most common model types used in transportation planning and decision-making include: 1) gravity models; 2) input-output models; 3) computable general equilibrium models; 4) integrated land-use transportation models; and 5) hybrid models, such as Regional Economic Models, Inc. (REMI), the Transportation Economic Development Impact System (TREDIS), or Oregon DOT’s State Wide Integrated Model (SWIM). This section provides an overview of these models. It also includes a brief description of alternative assessment approaches that do not rely on modeling.

### Summary Review of Models and Methods

The approaches and models presented in this section are summarized in Table 16. The table includes a brief description of the approach, identifies the specific questions being addressed, and assesses the extent to which it is used in transportation planning and forecasting, or in the assessment of economic development impacts.

Table 16: Summary of Approaches and Models

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Approach or Model** | **Brief Description** | **Specific Questions Being Addressed** | **Current Usage** | |
| **Planning & Forecasting** | **Economic Assessment** |
| Gravity models | Application of Newton's law of universal gravitation to allocate pre-determined growth in employment and population. | How will future population and employment be distributed? How would a change in accessibility affect the location of households and firms? | Frequently  used | Rarely  used |
| Input-Output models | Use of statistical tables of inter-industry transactions to estimate the indirect and induced effects of changes in spending or production costs. | What are the total impacts of a change in spending on a regional or local economy? How does a change in spending in one industry propagate through the economy? | Rarely  used | Frequently  used |
| Computable General Equilibrium (CGE) models | Combination of input-output tables with system of equations to represent behavior and resource constraints. Use of market-clearing mechanisms to simulate equilibrium. | How would a national or state economy react to large investment projects or policy changes? How would employment, prices, taxes, imports and exports adjust to a “shock”? | Generally  not used | Rarely  used |
| Integrated land-use transportation models | Integration of travel model and land-use forecasting tool to simulate “feedback cycle.” Use of random utility theory to describe and predict location choices. | How do changes in accessibility affect land use? How do changes in land use affect accessibility and transportation system performance? How would a transportation project or policy alter location choices? | Sometimes used | Rarely  used |
| Regional Economic Models, Inc. (REMI) | Hybrid model, combining elements of input-output systems, CGE models, and regional econometric models. | What would be the impacts of a program, project, or policy on the economy of a state, region, or county? | Sometimes used | Frequently  used |
| Transportation Economic Development Impact System (TREDIS) | Hybrid model, combining elements of input-output systems and econometric models. | How would a transportation project improve travel conditions and market access, and help stimulate the regional economy? | Generally  not used | Frequently  used |
| Oregon DOT’s State Wide Integrated Model (SWIM) | Hybrid model, combining elements of land-use, transportation, and economic simulation models, for statewide applications (Oregon). | What are the potential effects of transportation and land-use policies, programs, and projects on travel behavior, location choices, and economic activity? | Rarely  used | Rarely  used |
| Real Estate Market Analysis | Use of market research, interviews and stakeholder elicitation techniques to identify opportunities for development. | Which economic development opportunities could be leveraged by a transportation project? What are local property developers and stakeholders expecting? | Frequently  used | Frequently  used |
| Case Study Findings and Benefit-Transfer | Application of benefit-transfer methods to derive reasonable estimates of potential economic development impacts. | Based on similar projects at other sites and “analysis by analogy,” what range of economic impacts can be expected at a project site? | Generally  not used | Frequently  used |

### Gravity Models

Gravity models derive their name and premise from Isaac Newton's law of universal gravitation (U.S. DOT, 1977). Newton's law states that any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the distance between them. In social sciences, gravity models are used to describe and predict behaviors that mimic the gravitational interactions described in Newton’s law. The models typically contain some elements of mass and distance, which lends them to the metaphor of physical gravity (Wikipedia). For example, in macro-economics, a gravity model of international trade would predict bilateral trade based on the distance between two countries and their respective economic sizes (e.g., Gross Domestic Product)[[8]](#footnote-8). In transportation planning, the relative attractiveness of a location as a destination for travel would be modeled as a function of its mass (measured in square footage, population, or employment) and the distance or travel time to other similar regional destinations (NCHRP Report 466).

Gravity models are typically integrated in larger, more sophisticated models, and used in conjunction with other procedures and data. For example, in a four-step travel demand model, the algorithm used in the trip distribution step (to help determine where generated trips are attracted) is often specified as a gravity model.

With respect to economic development, gravity models can be used to forecast the location of future concentrations of households and firms following a change in regional accessibility. The approach is described in these terms in NCHRP Report 466:[[9]](#footnote-9)

*“This method allocates pre-determined growth in employment and population for a study area to subareas based on mass (the presence of attractors such as population, employment, vacant land, and other factors) and friction (distance between attractors in travel time). Control totals used for allocation can be developed using other forecasting techniques, or preferably the totals can be based on accepted forecasts developed by state or regional planning agencies.”*

NCHRP Report 466, page 77

In the assessment of location choices, factors other than distance and travel times may be considered as well, including housing costs, crime rates, the quality of public services (e.g., schools), and the presence of natural and man-made amenities. As noted in the NCHRP report, when adding other factors to a gravity model, care should be taken to establish relationships between the candidate variables by assigning weights. Weighting can be achieved through regression analysis or discussions with stakeholders and local experts (NCHRP Report 466, page 78).

Implementation of a gravity model to assess the economic development impacts of a transportation project would most likely be done within an existing software package. A gravity model of household locations, for example, could be implemented within the Open Platform for Urban Simulation (OPUS) developed by the University of Washington and University of California at Berkeley:

*“One could implement a wide array of models in OPUS (…). For example, one could create an OPUS project with one model that implements a simple gravity model for locating households, and uses only a zonal table with constraints, a zone-to-zone travel time table, and a set of control totals as inputs. In such a case, the data requirements would be only those tables required by the gravity model.”*

University of California Berkeley and University of Washington (2011), page 111

### Input-Output Models

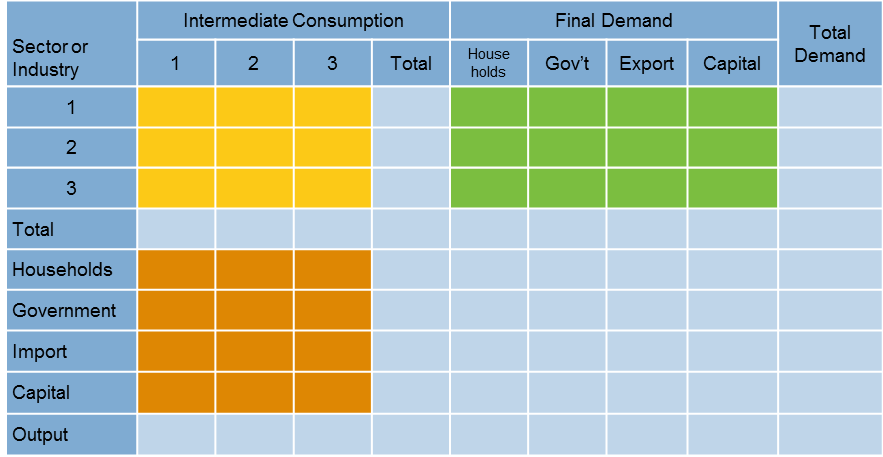
Input-output models are a class of economic models specifically designed to trace the impacts of a change in final demand (e.g., government spending) in one sector of the economy on the demand and output of all other sectors or industries. They can also be used to assess how reductions in production costs in one industry affect the rest of the economy. In transportation, input-output models are often used to estimate the economic impacts of a change in spending in the construction or transportation sectors (e.g., construction of a new transportation facility, increase in operating and maintenance expenditures), or to simulate the effects of user benefits (e.g., travel time saving, reductions in fuel consumption) on the broader economy.

In the estimation of economic impacts, input-output models typically consider the direct effects of an action, such as increased spending (e.g., construction workers directly employed at a site), as well as its “flow-on” effects in the economy. Thus, total economic impacts are calculated as the sum of direct, indirect, and induced effects, where:

* Direct effects are changes in economic activity occurring as a direct consequence of the action (e.g., decision to invest);
* Indirect effects are changes in economic activity resulting from changes in sales from suppliers to directly-affected businesses; and
* Induced effects are changes in economic activity resulting from spending by workers of directly and indirectly affected businesses.

Technical coefficients known as “economic multipliers” describe the relationship between direct, indirect, and induced effects. They indicate the overall change in economic activity resulting from successive rounds of spending and re-spending. Multipliers can be expressed in relation to output (business sales), income, or employment. Thus, with output as a measure of economic activity, a Type I multiplier is the ratio of direct plus indirect output changes to the direct output change. A Type II multiplier is the ratio of direct plus indirect plus induced output changes to the direct output change. The estimation of economic multipliers is based on a set of input-output transactions tables tracing inter-industry purchases and sales within a study area. This is illustrated in the figure below, where the demand for an industry’s product is presented in rows (sum of intermediate consumption plus final demand), the output (sales) of an industry is shown in columns, and output equals total demand within each industry.[[10]](#footnote-10)

Figure 10: Simplified Representation of an Input-Output Transactions Table



*Source: Adapted from Scottish Government (2006)*

Input-output models are available as standalone modeling systems with varying degrees of detail (e.g., number of industries; geographic granularity) and sophistication (e.g., representation of household consumption expenditures and options for the estimation of Type II multipliers; use of Social Accounting Matrix (SAM) in lieu of input-output table).[[11]](#footnote-11) Examples of such systems include IMPLAN (IMpact analysis for PLANning), commercially available through the IMPLAN Group LLC (formerly MIG, or Minnesota IMPLAN Group); or RIMS-II (Regional Input-Output Multiplier System), available through the Bureau of Economic Analysis. In addition, input-output transactions tables are often integrated within more sophisticated economic simulation models, including computable general equilibrium models or hybrid models (such as REMI or TREDIS).

The limitations of input-output models for assessing the economic development impacts of transportation projects have been documented in a number of publications. Among them is the fact that input-output analyses are often completed while ignoring potential “displacement” effects. Displacement effects arise when resources used in one project (or as a result of one project) are drawn away – in part or in full – from other productive uses (Wallis, 2009). Ignoring displacement effects tends to overstate the (positive) economic impacts of projects. To address this issue, best practice recommends that both gross and net economic impacts be calculated and reported; where gross impacts represent the effects of spending funds from both outside sources and local sources, without considering the impacts of spending local funds alternatively, on other purposes; whereas net impacts represent the effects of spending outside funds inside a local economy, after accounting for the impacts of spending local funds alternatively (CUTR, 2013).

All this considered, some economists have proposed to interpret the results of an input-output analysis as an “upper-bound measure” of the activity resulting from the increased use of underutilized resources (Duncan, 2001).

The use of input-output models is generally not recommended for the prioritization of transportation projects. Input-output models produce estimates of total economic impacts, measured in terms of business sales, value added, or employment. While growth in economic activity is typically considered to be a good thing, it is possible that such growth is not economically efficient as measured by standard efficiency rules (e.g., a benefit-cost ratio greater than 1 means that benefits exceed costs and the project is economically efficient). Thus, some or all of the increase in GDP estimated in a standard input-output model may arise through the consumption of more inputs (e.g., labor, land, and capital) as opposed to through higher productivity (Wallis, 2009). There is no guarantee that the economic value created through additional growth exceeds the social cost of resources used in production.

As noted above, input-output transactions tables are often embedded in macro-economic simulation models. These models also include other features and components to help address some of the limitations inherent to input-output modeling systems.

### Computable General Equilibrium Models

Computable general equilibrium (CGE) models, like input-output models, are simplified representations of the economy, which can be used to simulate the economic impacts of a project or policy[[12]](#footnote-12). CGE models are typically built on top of an input-output framework, and as such, share similar inputs (Wallis, 2009). However, they allow many more factors or dimensions to vary (including prices, labor productivity and wages, capital utilization rates, and prices), and explicitly account for budgetary constraints and resources availability. The phrase “general equilibrium” implies that the model considers multiple markets and economic sectors at once, and provides estimates of impacts that meet some market equilibrium conditions (e.g., supply equals demand). It is also used in reference to “general equilibrium” theory, a mathematical construct demonstrating the existence of a system of prices that equalizes all markets (i.e., aggregate demand equals aggregate supply, for all commodities in the economy), under perfect competition.

A CGE model is generally comprised of a set of equations describing how economic agents (e.g., consumers, producers, investors) – and indirectly markets – respond to changes or “shocks.” The parameters of these equations (e.g., elasticity coefficients) are typically estimated econometrically, with actual data, during model development. An input-output table or social accounting matrix is used to represent commodity flows and other economic transactions between sectors and agents, in a given year. Exogenous macro-economic forecasts (developed from another external model) are used to simulate future economic conditions in the base case, without the project or policy.

The United States Applied General Equilibrium (USAGE) model, for example, includes input-output accounts for 535 industries and 539 commodities, and a system of equations representing consumer, producer, government, and financial sector behavior (Puckett, at al, 2015). Data sources used in the development and calibration of these components include: Bureau of Economic Analysis national income and product accounts, input-output accounts, and balance of payments data; Department of Commerce trade flow data; and Department of Agriculture value-added data, from the Agricultural Resource Management Survey. Future baseline conditions are simulated on the basis of macro-economic forecasts prepared by the Congressional Budget Office, the Department of Agriculture, and the Bureau of Labor Statistics; as well as demographic projections from the Census Bureau. The USAGE-Hwy model uses estimates of benefits from the Highway Economic Requirements System (HERS) model for a given level of highway capital spending, at the national level.

As noted above, a distinguishing feature of CGE models is their ability to recognize constraints, in particular in terms of resource availability. A transportation project or policy that increases the demand for labor in a sector of the economy where unemployment is low, for example, would result in an increase in real wages, followed possibly by an increase in prices, capital-labor substitution, immigration, or any combination of these effects. Most CGE models also consider the fiscal impacts of government spending: an increase in spending in the short run, for example, might lead to increases in taxes in the long run, which – depending on how people form their expectations (e.g., do they expect that current policies will stay in place, be reversed, etc.) – might lead to immediate or gradual reductions in consumption and investment. Finally, most CGE models account for international transactions and can simulate adjustments in exports and imports through the foreign exchange market (Dwyer et al., 2004). Some models also recognize the imperfect substitutability of imported and domestic goods and services, the so-called Armington assumption (Dixon et al., 2013).

CGE models produce a variety of results, including a range of macro-economic variables (e.g., GDP, consumption, employment, imports and exports) and indicators of economic activity for individual industries. CGE models can also produce estimates of welfare gains, either directly (through changes in consumer surplus calculated within the model), or indirectly (through changes in personal income or consumption expenditures interpreted as changes in welfare, outside the model).

In simulating the economy’s response to a project or policy, CGE models can be “comparative-static” or “dynamic.” These define two broad categories of models. Comparative-static models simulate two future versions of the economy, at one point in time: a future version with the project or policy, and a future version without. Estimates of economic impacts (or benefits) are calculated as the difference between these two versions. For example, employment impacts would be estimated as the difference between employment in a future year with the project (or policy) and employment in the same year, without. Dynamic CGE models, in contrast, simulate each variable through time. They can account for gradual adjustment processes, and relationships between stocks and flows. The USAGE model, for example, can represent partial economic adjustments brought about by “sticky” wage rates and capital utilization rates (USDOT/Volpe, 2013), and thereby simulate slack in the economy. And dynamic CGE models typically use estimates of capital stocks and depreciation rates to predict investment decisions.[[13]](#footnote-13)

One important limitation is that CGE models are most effective at a broad geographic scale, either nationally or statewide. Revisions to accommodate lower scales (e.g., regional or local) are costly and challenging, in particular because of data limitations and substantial calibration efforts. In addition, CGE models are not necessarily well suited to simulate the impacts of small or medium-sized projects. As noted in the literature:

*“As the development of CGE models involves considerable time and expense, policymakers will need to be certain that information on macroeconomic outputs is of sufficient importance to justify the creation and maintenance of such models. Given this and the fact that transport projects are typically small in relation to the size of developed economies, it is likely that only the largest projects would require development and maintenance of such models.”*

Wallis (2009), page 54

Overall, CGE models are better able to simulate economic interactions and represent a more sophisticated approach than input-output models. Their use, however, remains very limited, at least partly due to the time and expertise required to use them, in particular for transportation planning and decision-making in the United States. This makes their current usefulness as a recommended approach to state, local, and regional entities for estimating economic development benefits of transportation projects for quite limited.

### Integrated Land-Use Transportation Models

Integrated Land Use Transportation (ILUT) models (also known as Land-Use Transportation Interaction or LUTI models) examine the interactions between transportation performance (e.g., accessibility, mobility) and the location decisions of various economic agents, including households, firms, real estate developers, and transportation suppliers (SACTRA, 1999). They attempt to predict the effects on land use of changes in the price, quality, and availability of transportation, as well as the feedback effects of changes in land use on transportation systems (Wallis, 2009). The land-use transportation feedback cycle that ILUT models seek to describe is illustrated in Figure 11, reproduced from Wegener (2004).

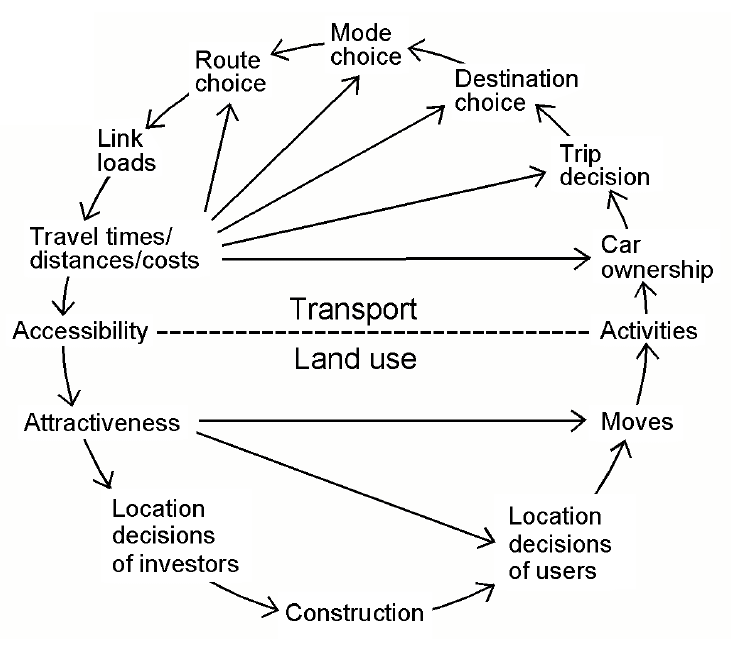
The literature on ILUT models is vast and growing. As noted in Safirova (2011), a variety of models are included in this category. ILUT models have been developed by academics, research centers, and consultancies. They include standardized modeling platforms applicable to a broad range of contexts, and simulation models calibrated for a specific region or metropolitan area. The models also vary in structure (unified vs. composite), spatial resolution (mesoscopic vs. microscopic), treatment of time (comparative-static vs. dynamic), or in the determination of land prices (endogenous or not). As noted in Wegener (2004), however, all state-of-the-art ILUT models rely on the same theoretical foundations to describe and predict the behavior of economic agents: random utility or discrete choice theory[[14]](#footnote-14).

Figure : The Land-Use Transportation Feedback Cycle

NCHRP Report 466 provides an overview of ILUT models available for implementation in 2002 (when the report was first published). For each model, the report offers a brief summary of the model’s origin and structure, examples of applications, data requirements, advantages and disadvantages, and an estimate of the costs and resources required for implementation. The ILUT models described in the report include: ITLUP, the Integrated Transportation and Land-Use Package developed by Steve Putman (University of Pennsylvania); MEPLAN, an integrated planning package developed by Marcial Echenique & Partners; TRANUS (Transporte y Uso del Suelo), maintained by a Venezuelan transportation planning group, Modelistica; METROSIM, a microeconomic land-use and transportation model developed for the New York Metropolitan Area by Alex Anas (State University of New York at Buffalo); and URBANSIM, a microeconomic model of location choice of households and firms, created by Paul Waddell and a team of researchers at the University of Washington. NCHRP Report 466 also identifies a number of in-house, operational models developed by metropolitan planning organizations to meet specific forecasting needs without being fully integrated. As noted in the report, these models contain elements that may be useful in the assessment of transportation projects (page 86). They include: CUF (California Urban Futures), TELUS (Transportation, Economic, and Land Use System), SCALDS (Social Cost of Alternative Land Development Scenarios), and Smart Growth Index (SGI), a GIS sketch-model for simulating alternative land-use and transportation scenarios developed for the U.S. Environmental Protection Agency.

Wegener (2004) reviews and compares a total of twenty ILUT models (including those described in NCHRP Report 466), against nine criteria (comprehensiveness, model structure, theoretical foundations, modeling techniques, dynamics, data requirements, calibration and validation, operationality, and applicability). These models include: ILUTE, an integrated urban modeling system of land development, location choice, and activity-based travel developed at several Canadian Universities; PECAS, the Production, Exchange and Consumption Allocation System developed at the University of Calgary; MUSSA, a land-use model developed specifically to interact with ESTRAUS, a four-step transportation model for Santiago, Chile; and START/DELTA, a strategic, integrated transportation and land-use/economic modeling system developed by a group of UK consultancies. Wegener finds significant variations across models against most criteria, and remarks that the transportation sub-models used in most current ILUT packages do not apply state-of-the-art activity-based modeling techniques – but rely instead on the traditional four-step approach (page 12). He also observes that the spatial resolution of current models is often too coarse to address neighborhood-scale issues (e.g., air quality).

The development and/or application of ILUT models typically require a significant data collection effort. The input data needed to use URBANSIM, for example, include[[15]](#footnote-15):

* Employment data, in the form of geocoded business establishments;
* Household data, merged from multiple Census sources;
* Parcel database, with acreage, land use, housing units, nonresidential square footage, year built, land value, improvement value, city and county;
* City and county general plans;
* GIS overlays for environmental features such as wetlands, floodways, steep slopes, or other sensitive or regulated lands;
* Traffic analysis zones;
* GIS overlays for any other planning boundaries;
* Development costs; and
* Travel model outputs (including zone-to-zone number of trips by mode, time of day, and trip purpose; travel time by mode, time of day, and trip purpose; and generalized cost by trip purpose).

The use of URBANSIM in combination with a transportation model produces a variety of land use and demographic variables, generally summarized by zone, including: households by income, age, and size; employment by industry and land-use type; acreage by land use; dwelling units by type; square feet of non-residential space by type; and real estate prices. More generally, ILUT models can be used to estimate changes in population and economic activity (e.g., employment, business sales) resulting from a transportation project or policy.

For the purposes of this desk reference and tools, it is important to remember that most ILUT models would only re-distribute growth within a locality or region (overall growth, with and without the project, would be determined exogenously, outside the model), while other more sophisticated systems also recognize and simulate the effects of transportation cost savings on productivity and economic growth.

Finally, ILUT models can be used to develop estimates of welfare gains (with transportation data produced in the travel module, or estimates of “utility” derived through application of discrete choice theory) for benefit-cost assessment and project prioritization.

With respect to standard benefit-cost analysis, it is generally recommended to hold land use constant across scenarios, with and without a project or policy. The benefit-cost analysis is then used to assess the efficiency with which transportation needs are met under alternative courses of actions. Thus, according to the UK Department for Transport:

*“Both the without- and with-scheme cases should include ‘near certain’ and ‘more than likely’ land-use changes (e.g., new housing or employment developments) (...). In all cases there should be no difference in land-use between the without- and with-scheme cases.”*

UK DfT (2014), page 5

When changes in land use and other structural effects are expected to be large, however, the use of integrated land-use transportation modeling techniques is recommended. The measurement of user benefits in this case should be based on disaggregated, variable trip tables whereby the effects of, and benefits associated with diverted and induced travel can be estimated. This is rarely done in the United States.

### Hybrid Models

This fifth class of models combines many features and characteristics of the previous four groups. Three examples of hybrid models are described below: REMI, TREDIS, and Oregon DOT’s Statewide Integrated Model, SWIM.

#### Regional Economic Models, Inc. (REMI)

The developers of REMI describe their model as “a dynamic forecasting and policy analysis tool that can be variously referred to as an econometric model, an input-output model, or even a Computable General Equilibrium model” (<http://www.remi.com/the-remi-model/overview>). There are in fact four different REMI models: PI+, TranSight, Tax-PI, and Metro-PI. All share the same core capabilities and resources. Summaries (drawn from descriptive material available online) for first two models, PI+ and TranSight, are include below.

* PI+ (formerly Policy Insight) is a general economic forecasting and policy analysis tool. The model includes an input-output transactions table and thousands of simultaneous equations organized into five major blocks: 1) output and demand, 2) labor and capital demand, 3) population and labor supply, 4) compensation, prices, and costs, and 5) market shares. The model is dynamic, with forecasts and simulations generated on an annual basis, and behavioral responses to compensation, price, and other changes. The model recognizes the spatial dimension of the economy, and accounts for the productivity gains resulting from the concentration of activity in urbanized areas, and from the clustering of industries. Finally, the model simulates long-term general equilibrium between supply and demand, through adjustments in prices, consumption, imports, exports, and other factors.
* TranSight was specifically designed for the evaluation of transportation projects and policies. It facilitates the use of travel demand model output (such as travel cost savings or changes in vehicle miles traveled) in the estimation of economic impacts. It is essentially an augmented version of PI+ to allow the integration of transportation data.

The PI+ model is calibrated to many sub-national areas, and is available in single- and multi-area configurations. Each calibrated area (or region) has economic and demographic variables, as well as policy variables so that any policy that affects a local economy can be tested (<http://www.remi.com/products/pi>). There are annual licensing costs that depend on the area size and model configuration.

#### Transportation Economic Development Impact System (TREDIS)

TREDIS is an integrated decision-support system for estimating the economic impacts of transportation projects. The system also includes a multi-modal benefit-cost analysis module (MBCA) and a public-private financial analysis module. TREDIS uses a dynamic economic simulation to estimate long-range impacts with sensitivity to factors that can be affected by transportation – such as changes in rural accessibility, urban congestion, intermodal connectivity and reliability, as well as changes in traffic volumes and speeds.

TREDIS also includes an Economic Adjustment module that applies dynamic, multi-regional (e.g., cross-county) economic impact simulation techniques to estimate impacts on employment and income over time. The module incorporates the IMPLAN input-output model, and uses a series of economic geography and econometric response factors to account for effects on labor and delivery market areas. It also builds upon trade flows and spatial access data from Moody’s, ESRI and the U.S. Bureau of Economic Analysis.

In TREDIS, the economic impact analysis takes into consideration: 1) the share of the transportation benefits that accrue to businesses (or are otherwise spent in the economy); 2) the mix of industries where transportation benefits are realized and the types of businesses they trade with; 3) the share of those benefits that occur within the region versus outside the region; and 4) for benefits that accrue within the region, the share of the money spent on local businesses versus outside firms. TREDIS recognizes four categories of impacts:

* **Impacts from Improved Transportation Efficiency:** the reduction in household and business transportation costs implies that more can be spent on locally produced goods and services, or investment;
* **Impacts from Improved Market Access:** the reduction in transportation costs implies that businesses can reach a broader set of suppliers and customers, which in turn helps reduce their production costs and expand their sales;
* **Business Attraction:** the reduction in transportation costs leads to changes in business locations and land use; and
* **Construction Impacts:** the transportation project itself creates a temporary increase in employment in the construction sector, and associated activity.

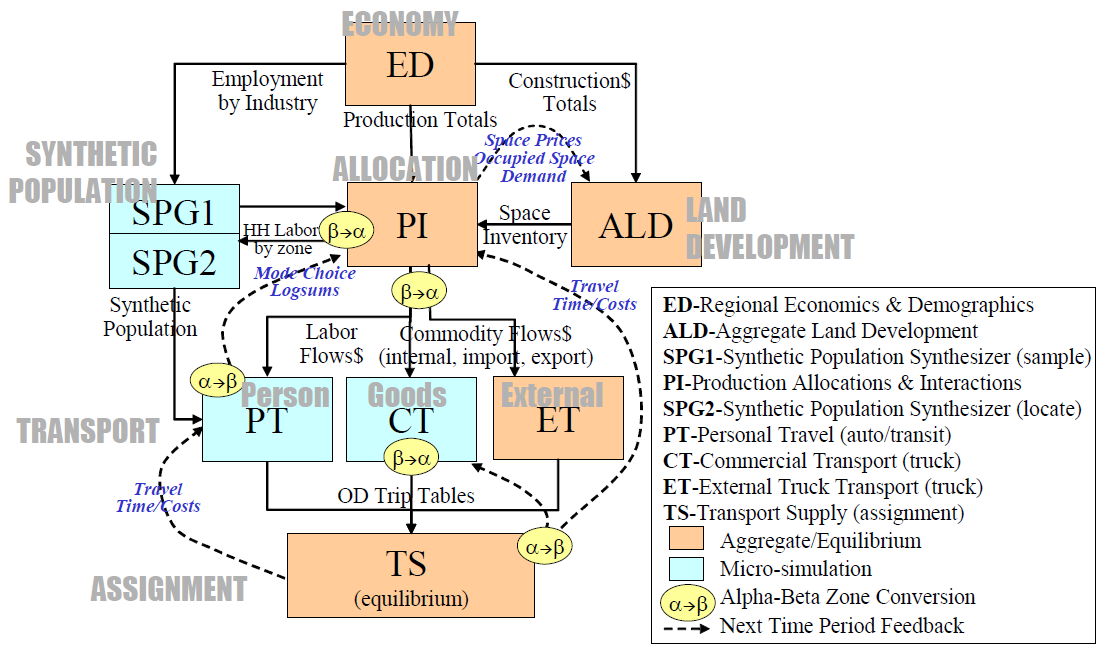
All four categories of effects can be estimated within TREDIS, with proprietary algorithms applied to regional or local economic data. The results produced by TREDIS are shown at the local and regional levels and the calculations used to create the results are traceable by the user, which gives the tool some transparency. The impacts can also be viewed across different stakeholders, study areas or time periods. There are annual licensing costs for TREDIS that depend on the area size and model configuration.

#### Oregon DOT’s State Wide Integrated Model

Oregon’s State Wide Integrated Model (SWIM) is a statewide, integrated land-use, transportation, and economic model. SWIM uses the PECAS economic input-output activity allocation framework, an aggregate model of spatial development, and micro-simulation models of freight and passenger travel. It contains a set of eight separate but highly connected modules:

* The Economics and Demographics module, which determines mode-wide production activity levels, employment, and imports/exports.
* The Synthetic Population Generator module, which samples household and person demographic attributes (SPG1) and assigns a household to an alpha zone (SPG2).
* The Aggregate Land Development module, to allocate model-wide land development decisions among study area a-zones considering floor space prices and vacancy rates.
* The Production allocations and Interactions module determines commodity.
* The Person Travel module, which generates activity-based person trips for each study area person in the synthetic population, during a typical weekday.
* The Commercial Transport module, that generates mode split for goods movement flows, and generates truck trips, combining shipments and possible transshipment locations, for a typical weekday.
* The External Transport module, which generates truck trips from input O-D trip matrices representing import, export (within 75 miles) and through movements based on PI and external station growth rates.
* The Transport Supply module assigns vehicle, truck, and transit trips (separately) to paths on the congested transport network for a 24-hour period, generating time and distance skims for AM and off-peak periods.[[16]](#footnote-16)

Figure 12: Oregon Statewide Integrated Model (SWIM2) Structure



*Source: Weidner, Knudson, and Hunt (2009)*

As noted in NCHRP Report 606, SWIM can be used to support land-use and transportation decision-making and develop long-term economic, demographic, passenger travel, and commodity flow forecasts at the statewide and sub-state levels. Specifically, it can be used to assess the potential effects of transportation and land-use policies, programs, and projects on travel behavior and location choices.

The model also produces outputs that can be used in other analysis packages for assessing transportation system performance (NCHRP Report 606, page 119). SWIM is designed to address questions at a relatively large scale, and is best suited to simulate the impacts of major transportation projects or programs. It can also be used to describe and predict statewide trends that affect local areas (e.g., interstate traffic passing through a local jurisdiction) (ODOT, 2011).

### Other Methods

This last sub-section provides an overview of methods other than modeling, which can be used for assessing the economic development impacts of transportation projects. These include real estate market analysis and the use of case study findings in benefit-transfer.

#### Real Estate Market Analysis

This general approach involves working with local economic development professionals, real estate developers and subject matter experts to assess the potential economic development benefits of a proposed project or policy. Various elicitation techniques, ranging from telephone interviews to Delphi methods and workshops, may be used to: 1) obtain information on existing market conditions; 2) assess the availability of land; and 3) identify opportunities for transportation-induced development or re-development, by zone. This information can be combined with local real estate and socio-economic data – and possibly processed in spreadsheet-based simulation models – to develop sketch-level projections of real estate development in terms of properties, square footage, and market value under alternative scenarios (e.g., with and without the project). The outcomes of this analysis can then be used to quantify the economic impacts of the project, in terms of employment, labor income and other measures of economic activity. This can be done through estimates of employment per square-footage of office, retail, or industrial space, and average compensation per employee, derived from regional or county-level economic data.

#### Benefit-Transfer Method

Under this approach, empirical evidence on economic development at other sites would be used to develop estimates of incremental economic activity at the project site. For construction projects, analysts may rely on the Transportation Project Impact Case Studies (EconWorks) System. The EconWorks system is a searchable database of past projects and their observed impacts on economic development. It can be used as a predictive tool to estimate a range of likely impacts for new projects. The system includes empirical evidence on 105 projects, including Beltway (8), Bridge (10), Bypass (13), Connector (8), Interchange (12), Industrial Access Road (7), Major Highway (14), Widening (9), Freight Intermodal Terminal (10), and Passenger Intermodal Terminal (9) projects. Projects are spread across the Nation, and organized in five regions. The evidence from EconWorks includes project characteristics, impact metrics, and a set of control variables (e.g., rural vs. urban location, topography, economic distress level). This “analysis by analogy” or “benefit-transfer” approach can be used for early-stage project assessment (SHRP2 Capacity Project Brief, 2012).

### Summary of Uses and Limitations of Methods for Estimating Economic Development Impacts of Transportation Investments

Many of these tools require coordination or use within other models, some of which must be customized. Due to cost and complexity, many are not currently very accessible to state and local transportation decision makers.

As noted above, gravity models are typically integrated in larger, more sophisticated models, including travel demand models. Given their cluster approach to the location/re-location they may not be very useful for larger geographic areas.

Input-output models of various types are widely available, but they have limitations (do not incorporate fiscal or labor constraints, assume fixed industry relationships and productivity) which hamper the usefulness of their results. They also do not assess the economic growth against economic and social costs so can not determine if a project is ‘economically efficient’.

CGE models are not well suited to small or medium-sized projects and are most effective at a broad economic scale (opposite limitation from gravity models). In addition, their use in the US remains very limited, especially for transportation.

As noted above, it is important to remember that most ILUT models would only re-distribute growth within a locality or region. Additionally, for large expected effects, the measurement of user benefits can be based on disaggregated, variable trip tables, which is rarely done in the US.

Several hybrid models are available to state and local agencies and economic development benefits are generally estimated based on user benefits (typically calculated via a BCA). Other approaches, such as real estate market analyses benefit-transfer methodologies, do not lend themselves to automation and would be thus difficult to include as part of a tool beyond general guidelines and instructions on how to conduct such an analysis.

# Appendix: Structure and Logic Diagrams from V2I Benefits Estimation Tool (VBET)

As noted in Chapter IV ‘V2I Benefits Estimation Tool (VBET)’ (page 49), VBET includes structure and logic (S&L) diagrams each benefit category that describe the inputs, cause-and-effect relationships, and outputs for the sketch-planning tool. An S&L diagram illustrates how a metric is estimated. It is the graphical representation of an equation, where each box is a variable or parameter (e.g., input, model coefficient, intermediate output or final output) and links between boxes are operations (e.g., add, multiply or divide).

This appendix reproduced the S&Ls for the BCA and EIA calculation in VBET.





# Glossary

|  |  |
| --- | --- |
| ***Accessibility*** | Accessibility measures the relative ease that a person can reach or approach a destination. |
| ***Agglomeration Impacts /Benefits*** | The term agglomeration impacts (or benefits) refers to economies of scale that would arise from improved mobility or concentration of economic activity that arise when firms locate near each other. |
| ***Automated Vehicle*** | Automated Vehicle, which can also be colloquially referred to as “self-driving” vehicles are defined by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) as “those in which operation of the vehicle occurs without direct driver input to control the steering, acceleration, and braking and are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode.” ([http://autocaat.org/Technologies/ Automated\_and\_Connected\_Vehicles/#sthash.KJHsChHk.dpuf](http://autocaat.org/Technologies/Automated_and_Connected_Vehicles/#sthash.KJHsChHk.dpuf)) |
| ***Base Case*** | In transportation analyses, the base case (or no build) represents the existing conditions, including the expected changes that would occur without the transportation project during the period of analysis. |
| ***Benefit-Cost Analysis (BCA)*** | Benefit-Cost Analysis (BCA) is well-established methodology that compares the potential benefits of a project with the estimated costs of the project over a specified period of time. If the potential benefits outweigh the expected costs, the analysis suggests that the project will benefit society in general. BCA relies on monetizing non-market goods and services to make them comparable to market goods. It is sometimes referred to as Cost-Benefit Analysis. |
| ***Benefit-Cost Ratio*** | A benefit-cost ratio (B/C) is one of the key metrics that result from a benefit-cost analysis. It is the present value of benefits divided by the present value of costs for a defined analysis period. A benefit-cost ratio greater than one implies that the benefits are greater than the costs, and a ratio less than one implies that the costs exceed the benefits. |
| ***Build Alternative*** | In transportation analyses, the build alternative represents the project or program of projects being evaluated. |
| ***Connected Vehicle*** | Connected vehicles are vehicles that use any of a number of different communication technologies to communicate with the driver, other cars on the road (vehicle-to-vehicle [V2V]) or roadside infrastructure (vehicle-to-infrastructure [V2I]). |
| ***Consumer Surplus*** | Consumer Surplus is an economic measure of the value consumers derive. It is calculated as the difference between what consumers are willing to pay for a good or service relative and the actual price they pay. It is considered a social benefit. |
| ***Cost-Effectiveness Analysis*** | A Cost-Effectiveness Analysis compares alternatives to reaching the same end so as to determine which would achieve the desired outcome at the lowest total cost. |
| ***Dedicated Short Range Communications (DSRC)*** | Dedicated short-range communications are one-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use. |
| ***Depreciation*** | Depreciation refers to the loss of value in an asset over time. |
| ***Direct Impacts*** | Direct impacts of a transportation project are the changes or impacts to users or local or regional area most directly from the use of the transportation facility, such as changes in travel time, vehicle operating costs, emissions, noise, etc. |
| ***Discount Rate*** | The discount rate is an annual percentage factor that reflects the time value of money (or opportunity cost) or other resources associated with a project. |
| ***Double-Counting*** | Double counting is an error in which a particular transaction or effect is counted twice. |
| ***Economic Competitiveness*** | The ability of a firm, sub-sector, or region to sell and supply goods and services in a given market, in relation to the ability and performance of other firms, sub-sectors or regions competing in the same market. |
| ***Economic Impact Analysis (EIA)*** | Economic impact analysis is form of economic analysis examines indirect, local economic impacts of an investment (such as a new road) or policy intervention (such as geographic-based tax incentives). The results can be estimates of changes in jobs, tax revenue, wages, output, property values and even changes in tourism, housing and migration patterns. |
| ***Economic Multipliers*** | Economic Multipliers are factors that indicate the overall change in economic activity resulting from successive rounds of spending and re-spending and, therefore, capture the full impacts of changes in business transportation cost in the local economy on both the business side and the household side. |
| ***Economies of Scale*** | Economies of Scale refer to the economic advantages that arise due to larger size, output, or scale of operation. |
| ***Environmental Justice*** | Environmental justice refers to concerns of whether or how the negative impacts of some policies or activities might fall disproportionately upon minority populations and low-income populations. |
| ***Fiscal Impacts*** | Fiscal Impacts refers to the changes in tax revenues to a jurisdiction that arise from an event such as a transportation investment. |
| ***Generalized Cost*** | In transport economics, the generalized cost refers to the sum of the monetary and non-monetary costs of a journey. |
| ***Gross Regional Product (GRP)*** | GRP is the total market value of all final goods and services produced by all industries in a region within a given time period. |
| ***Gross State Product (GSP)*** | GSP is the total market value of final goods and services produced by all industries in the state within a given time period. |
| ***Highway Economic Requirements Model (HERS)*** | The Highway Economic Requirements Model (HERS) is a computer model developed for the Federal Highway Administration to help state and local governments in programming their highway resources. HERS contains routines to estimate the economic benefits of potential transportation projects, which can assist state and local governments develop highway investment programs and policies that maximize economic benefits relative to costs. |
| ***Indirect Impacts*** | Indirect impacts refer to the changes in economic activity in the area (local or regional) that arise due to the direct impacts. |
| ***Induced Impacts*** | Estimated in economic impact analyses, induced effects are the increased sales within the region from household spending of resident workers associated with the direct and indirect impacts of the project under analysis. |
| ***Life-Cycle Cost Analysis (LCC)*** | A life-cycle cost analysis (LCC) is a method for evaluating the total economic cost of a project over its project life and incorporates both initial costs and discounted future costs, including as user, maintenance, reconstruction, rehabilitation, restoring, and resurfacing costs. |
| ***Mobility*** | The ability of people to move about and make use of various transportation modes. See accessibility |
| ***Mode*** | The method of transportation by which people travel. |
| ***NEPA*** | The National Environmental Policy Act (NEPA) is a United States environmental law that promotes the enhancement of the environment and established the President's Council on Environmental Quality. Transportation projects must undergo a process under NEPA to assess the expected social, economic, and environmental impacts. |
| ***Net Present Value (NPV)*** | Net present value (NPV) is one of the key result metrics from a benefit-cost analysis. NPV is calculated as total benefits over the improvement’s expected life (or other period of analysis), discounted to the present, less total costs over the improvement’s expected life (or other period of analysis), discounted to the present. If benefits are positive, then expected benefits are greater than expected costs. |
| ***No Build Alternative*** | In transportation analyses, the no build refers to the existing conditions in an area, including the expected changes that would occur without the transportation project during the period of analysis. |
| ***Payback Period*** | The payback period is the length of time required to recover the cost of an investment. |
| ***Qualitative Analysis/Benefits*** | A qualitative analysis of a transportation project assesses aspects or impacts of the project that are not quantified. |
| ***Quantitative Analysis/Benefits*** | A qualitative analysis of a transportation project estimates aspects or impacts of the project that can be measured. |
| ***Rate Of Return*** | The internal rate of return is a measure represents the discount rate necessary to yield a net present value (NPV) of zero from a project’s benefit and cost stream. |
| ***Risk Analysis*** | A risk analysis is the review of the risks associated with a particular event or action. It can include estimates of the impacts of certain uncertain aspects of the event or action. |
| ***Risk Analysis with Monte Carlo Simulation*** | Risk analysis with Monte Carlo simulation estimates a range of potential outcomes by varying numbers for key inputs randomly from a predefined range and then running the estimation simultaneously through the specified formulas of the analysis several thousand times. Commercial software is available to automate Monte Carlo modeling. The results are then arrayed to give a sense of the range of likely final results. |
| ***Secondary Costs*** | Secondary Costs are those costs separate from the direct costs of building and managing a project and can include costs, or “disbenefits,” to entities negatively impacted by a project. |
| ***Sensitivity Analysis*** | A sensitivity analysis assesses the potential impact of variability in individual inputs on final results of an analysis. The input or factor of interested is varied in the analysis and the change in final results of the analysis is examined. |
| ***Travel Time Savings*** | Travel Time Savings refer to value of the ability to make trips more quickly that arises due to a transportation change or investment. The difference in trip times is converted into dollar terms (monetized) using an estimate of the value of travelers’ time. |
| ***User Benefits*** | User benefits are the benefits that are experienced directly by the users of the transportation investment under study and can include travel time, vehicle operating cost, other travel costs, emissions, and avoided accidents. |
| ***Vehicle-To-Infrastructure (V2I)*** | Vehicle-to-Infrastructure (V2I) communications technologies use wireless exchange of data between vehicles and roadway infrastructure. |
| ***Vehicle-To-Vehicle (V2V)*** | Vehicle-to-Vehicle (V2I) communications technologies use wireless exchange of data between different vehicles on the road. |
| ***Wider Economic Benefits*** | Wider Economic Benefits cover economic benefits that go beyond those that are in standard Benefit-Cost Analysis, including agglomeration benefits, business reorganization, and technology adoption benefits. |

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1. Note that NCHRP 8-36-101 uses direct, indirect and “induced” (third level impacts “as workers, hired as a result of the direct and indirect impacts of the project, spend a portion of their increased earnings on additional goods and

   services”) in its discussion of economic impact analysis in a manner different from the other reports. (p 4.2) [↑](#footnote-ref-1)
2. It is worth noting that FHWA’s Economic Development webpage continues with a short description of tools or approaches for use by planners, including benefit-cost analysis, cost-effectiveness analysis, economic impact analysis, and publications by The National Cooperative Highway Research Program (NCHRP) and the SHRP2 program for estimating Wider Economic Benefits. [↑](#footnote-ref-2)
3. NCHRP 08-36-61 notes “This raises a concern that the factors on which transportation agencies make decisions are somewhat removed from factors set forth as important by communities in the goals and vision statements of transportation plans. This disconnect between community goals for quality of life and transportation goals quite naturally can lead to outcomes at the project and system levels that are poorly matched with community values.” Page 16. [↑](#footnote-ref-3)
4. National Highway Transportation Safety Administration, “Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application”, August 2014. DOT-HS-812-014. <http://www.nhtsa.gov/staticfiles/rulemaking/pdf/V2V/Readiness-of-V2V-Technology-for-Application-812014.pdf>. [↑](#footnote-ref-4)
5. <http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/transportation_satellite_accounts/index.html>. [↑](#footnote-ref-5)
6. Found at [http://ntl.bts.gov/lib/55000/55400/55443/AVBenefitFrameworkFinalReport082615\_Cover1.pdf](http://ntl.bts.gov/lib/55000/55400/55443/AVBenefitFrameworkFinalReport082615_Cover1.pd). [↑](#footnote-ref-6)
7. Adapted from SACTRA (1999), page 7 [↑](#footnote-ref-7)
8. This would be expressed as ; where *T* stands for trade flows between two countries *i* and *j*; *G* is a constant; *M* a measure of economic activity; and *D* the distance between the countries. [↑](#footnote-ref-8)
9. NCHRP 466 “presented a gravity-based framework, as one option for assessing the indirect effects of transportation projects.” [↑](#footnote-ref-9)
10. With final demand *Y* and total output *X*, the transactions table can be summarized with the following equation: ; where *A,* the “Direct Requirements” matrix, is obtained by dividing each cell in the intermediate demand quadrant (yellow area) by its column total. Rearranging, this can be expressed as or . Type I multipliers can be estimated as the sum of the values in each column of (I – A)-1, the Leontief Inverse Matrix. Induced effects and Type II multipliers can be calculated by expanding the direct requirements matrices (A) with an additional row for employee compensation (as a proportion of output), and an additional column for household expenditure (as a proportion of household income). [↑](#footnote-ref-10)
11. A Social Accounting Matrix is a matrix that presents the flows of all economic transactions, between different production activities, factors of production, and institutions that take place within a regional or national economy. [↑](#footnote-ref-11)
12. CGE models are also referred to as Applied General Equilibrium (AGE) models. [↑](#footnote-ref-12)
13. Other variants of CGE models include recursive-dynamic models, or dynamic stochastic general equilibrium models. [↑](#footnote-ref-13)
14. Random utility models represent choices between alternatives as a function of alternatives attributes, while accounting for differences in taste, unobserved attributes, and uncertainty. [↑](#footnote-ref-14)
15. Source: University of California Berkeley and University of Washington (2011) [↑](#footnote-ref-15)
16. Parsons Brinckerhoff, *Oregon Statewide Integrated Model (SWIM2)*, Draft Report version 2.5 [↑](#footnote-ref-16)