V2I Benefits Estimation Tool (VBET) Instructions

INTRODUCTION

The V2I Benefits Estimation Tool (VBET) is a user-friendly spreadsheet model to assist state and local agencies in assessing the potential benefits and economic impacts associated with implementing vehicle-to-infrastructure (V2I) connected vehicle (CV) technologies and applications. Given basic information for a V2I deployment, the tool allows the user to explore the potential benefits of V2I applications, prepare a benefit-cost assessment (BCA), conduct an economic impact assessment (EIA), or identify other tools and methods to assess the economic impacts of V2I applications. An accompanying desk reference provides information on the latest research into the benefits of V2I applications, approaches to analyzing the economic impact of operations strategies, methods for conducting economic analysis of V2I applications, and upcoming research and studies.

VBET is designed to work with a suite of other V2I decision-making tools:

- *Cost Overview for Planning Ideas & Logical Organization Tool (CO-PILOT)* – The Federal Highway Administration (FHWA) sponsored CO-PILOT provides a standardized listing of 56 V2I applications. This tool allows the user to prepare a high-level cost estimate for V2I deployment as part of preliminary planning.
- *AASHTO Near-Term V2I Transition and Phasing Analysis: Application Prioritization Tool* – This tool is part of a suite of tools developed by the American Association of State Highway and Transportation Officials (AASHTO) to support near-term V2I deployment. The prioritization tool allows the user to develop a list of suggested V2I applications through a series of questions.
- *AASHTO Near-Term V2I Transition and Phasing Analysis: Vehicle Life Cycle Cost Model (LCCM)* – A second tool in the AASHTO near-term V2I deployment suite, the LCCM helps the user estimate full lifecycle costs components, including initial deployment, maintenance, and replacement costs over a 20-year period.
- *AASHTO Near-Term V2I Transition and Phasing Analysis: Infrastructure Planning Tool* – A third tool in the AASHTO near-term V2I deployment suite, this planning tool assists the user in selecting the appropriate timing and phasing of V2I deployments.

The VBET user is expected to use these other tools or similar methods to select V2I applications, estimate the lifecycle costs of these deployments, and chose the appropriate timing or phasing of deployments before running VBET. The tool provides some capabilities to explore the literature on V2I benefits that may be helpful in selecting V2I applications.

VBET is organized by worksheet. The basic worksheets that most users will use are described in the table below. The other VBET worksheets contain detailed calculations. Most users will not reference these worksheets, but they are available for viewing by toggling the viewing mode. This is described later in the instructions.

Worksheet	Purpose
OpeningScreen	Startup screen providing the user with four options for using model
1. Impact	Automated literature review that shows the range of impacts for V2I applications
2. Identify	Questionnaire to help user select other economic tools and methods
3. ConductAnalysis	Initial economic analysis screen that allows the user to select BCA or EIA
3.1. BCA Inputs	Basic information for economic analysis, including V2I applications and setting
3.2. BCAPeneRate	V2I penetration rates for selected applications (V2I adoption curves)
3.3. BCAEfficacy	Efficacy adjustment factor (degree to which V2I applications deliver full benefits)
3.4. BCAResults	Summary results for the benefit-cost analysis
3.5. EIAInputs	Additional inputs required for economic impact analysis
3.6. EIAResults	Summary results for economic impact analysis
4. ModelInstructions	Reference guide for model (additional information provided in desk reference)
5. BCAParameters	Economic values, assumptions, and other parameters used in the tool
6.1. StudiesSummary	Summary of quantitative impacts from V2I studies
6.2. StudiesList	List of V2I studies included in the tool

The opening screen of the tool allows the user to select from among four primary capabilities:

- *Capability 1: Investigate Potential Impacts of V2I Applications* – allows the user to review existing V2I research and the potential impacts of V2I technologies. This capability is an automated literature review.
- *Capability 2: Identify Other Appropriate Economic Tools and Methods* – helps the user identify appropriate economic tools and methods for conducting economic analyses of V2I applications. This capability allows the user to find economic tools in addition to VBET. Tools that may be used to estimate V2I operational impacts (e.g., travel demand models or microsimulation models) are not included in the lists.
- *Capability 3: Conduct Economic Analysis of V2I Applications* – conducts a sketch-planning level BCA or EIA for one or multiple V2I applications. Most users will rely on this capability of the tool. Note that the BCA information must be provided before the economic impact can be calculated.
- *Capability 4: Get Help* – serves as a reference guide for VBET. These instructions are part of the get help capability. Additional information on the technical approach and calculations in VBET can be found in the accompanying desk reference.

By clicking on the appropriate button, the user is taken to the appropriate worksheet in the tool. The VBET worksheets are color-coded according to the four main capabilities:

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

At the bottom of the opening screen, the user has the option to select which worksheets are displayed in the model. Most users will select the **Simple** mode. In this default mode, the user sees only worksheets that require user inputs or display results (which is a subset of the worksheets shown in the table above). The user has the option of adjusting key parameters while using the simple mode.

In the **Advanced** mode, the user can adjust additional parameters for the BCA (i.e., the vehicle penetration rate and the efficacy of V2I applications), view the V2I literature and impacts included in the model, and adjust VBET parameters. The advanced mode shows all of the worksheets in the table above. The user also has the option to show all VBET worksheets by clicking on "Show Entire Model." The user can go to the opening screen and select a different mode to hide or unhide worksheets at any time, including during an analysis.

The tool can be navigated by selecting the desired worksheet tabs within the Excel workbook or by using a navigation bar located at the left side of each worksheet. The navigation bar looks like an outline and is organized by model capabilities. The navigation bar has built-in hyperlinks that allow the user to jump between sections of the model by clicking on a section of the outline. This feature is particularly useful while conducting a BCA or EIA.

Some worksheets include instructions that appear as purple boxes on top of user entry fields. These instructions provide additional information about the inputs expected. The instructions disappear when the user clicks on them. If the worksheet includes instructions, the navigation bar includes a button that allows the user to toggle the instructions on or off. All of the purple boxes are removed if the instructions are hidden.

INSTRUCTIONS

The user will begin any analysis by selecting a model capability using one of the four colored buttons on the opening screen. The tool automatically takes the user to the appropriate worksheet. While most capabilities use a single worksheet in the model, the capability to conduct an economic analysis of V2I applications requires multiple worksheets. Each of these spreadsheets are described in more detail below and organized by tool capability. The corresponding spreadsheet name is listed in **purple**. The user can go directly to this capability by selecting the appropriate worksheet tab or by using the navigation bar.

Capability 1: Investigate Potential Impact of V2I Applications ("1. Impact")

This worksheet allows the user to investigate the types of impacts (e.g., travel time, safety, emissions, and throughput) associated with V2I applications. The potential impacts listed come directly from the literature review described in the accompanying desk reference. The VBET development team has not tried to estimate benefits or extrapolate results beyond what is reported in the literature. This can create some apparent inconsistencies. For example, an application that reduces emissions may also reduce fuel consumption. However, if the study cited in the literature review did not estimate fuel consumption benefits, these benefits are not reported. These inconsistencies should diminish over time as the literature on V2I applications grows.

The tool allows practitioners to research and identify the potential impacts of various V2I applications. All impacts are reported at a high-level as a percent decrease in the costs associated with V2I

applications. Impacts that are expected to be associated with a particular V2I application, but were not supported in the available literature are reported as "unquantified benefits."

This worksheet allows the user to select one V2I application and an associated impact category at a time. After these selections have been made, the range of impacts observed in the literature will be displayed in the *Potential Impact* section of the workbook. To see another impact category, the user simply needs to select that category.

1. V2I Application

Select a V2I application from the dropdown list. The list is automatically populated with the names of V2I applications available in the tool.

2. Impact Category

Select an impact category from the dropdown list. This list automatically adjusts based on the V2I application to show only the names of impact categories with evidence in the literature.

3. Potential Impact

Review the potential impact in the box. A potential impact box turning light blue indicates the lack of quantified impacts in the current database. The tool will adjust as additional information is added to the literature review data available in the **"6.1. StudiesSummary"** worksheet. The user can see this worksheet in the **Advanced** mode.

Capability 2: Identify Other Appropriate Economic Tools and Methods ("2. Identify")

This worksheet allows the user to identify economic tools and methods other than VBET for conducting economic analyses of V2I applications. The worksheet guides the user to appropriate tools and methods by having the user select the desired geographic level of analysis and performance measures of interest.

The tools and methods are listed in VBET under three main categories:

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

VBET does not include tools that may be used to estimate V2I operational impacts (e.g., travel demand models or microsimulation models) in the lists. Additional information on the tools and methods suggested by VBET can be found in the accompanying desk reference.

1. Select Geography

Select one or multiple geographic scales of interest from the list by clicking on the corresponding checkboxes. Selecting "No Preference" will unselect all other options. Unselecting "No Preference" will automatically select all other options.

2. Select the Affected Measure

Select one or multiple measures of interest from the list by clicking the corresponding checkboxes. Selecting "No Preference" will unselect all other options. Unselecting "No Preference" will automatically select all other options.

3. Methods and Tools

Review the list of the methods and tools that may be appropriate to conduct the analysis. The list is populated based on selections in sections *1. Select Geography* and *2. Select the Affected Measure*. Clicking on one of the methods or tools causes the tool to provide a description of the method or tool in the description boxes.

4. Description

Review the two boxes in this section. The first box provides a description of the method or tool selected. The second box lists some of the questions that a selected method or tool can help to answer.

Capability 3: Conduct Economic Analysis of V2I Applications ("3. ConductAnalysis")

This worksheet allows the user to conduct an economic analysis of V2I applications. The user can conduct two types of economic analysis: benefit-cost analysis (BCA) and economic impact analysis (EIA). A BCA compares the user benefits (e.g., travel time savings and safety) of a V2I deployment with the costs of the deployment. An EIA shows the potential impact of the user savings on the state or regional economy. Conducting an EIA requires a BCA to be completed prior to starting EIA.

When the user selects "Conduct Economic Analysis of V2I Applications," the model takes the user to the opening page of the economic analysis section of VBET. This page is the main worksheet in a series of worksheets 3.1 through 3.5, which are described in more detail below. Note that if the user selects the simple model, worksheets 3.2 and 3.3 are not shown.

Select Type of Analysis

Select "Benefit-Cost Analysis" or "Economic Impact Analysis" from the dropdown list. If the user selects "Economic Impact Analysis," the model notes that an EIA requires the results of a BCA.

There are two buttons on this worksheet:

1. **Reset Inputs –** Press this button to clear all user inputs on economic analysis worksheets and restore default values. This allows the user to reset the tool to run another economic analysis. Note that the current version of VBET does not restore any formulas that may have been accidently modified or deleted by the user. It is suggested that the user keep a blank copy of the model to avoid any mistakes. The **Reset Inputs** button also activates any overlay instructions on the economic analysis worksheets.
2. **Start Analysis –** Press this button to start an economic analysis of the selected type ("Benefit-Cost Analysis" or "Economic Impact Analysis").

Benefit-Cost Analysis (BCA)

VBET allows the user to calculate a sketch-planning level BCA of V2I deployments. Four primary user benefits are considered in the analysis:

- Travel time;
- Safety;
- Vehicle operating costs (fuel and other costs); and
- Emissions.

VBET estimates the benefits of V2I deployments using percent improvements in each of these four benefit categories using values found in the research literature. The initial version of VBET includes impacts available at the time of its development. This research is expected to grow as V2I applications are deployed and impact values can be updated in the "6.1. StudiesSummary" sheet (which is unhidden in the **Advanced** mode).

The user can assess the impact of multiple V2I applications. Since no literature is available on the combined impacts of V2I deployments, VBET allows the user to select the appropriate method for combining applications (e.g., minimum impact, maximum impact, average impact, or cumulative impact).

For each V2I application, VBET calculates user benefits by comparing a No Build scenario with a Build scenario. The No Build scenario is based upon the travel characteristics and forecasts that the user inputs into the model. The user is expected to provide data for the appropriate level of analysis (e.g., spot location, corridor, or region).

VBET calculates the Build scenario by applying the impacts from the literature to the No Build scenario. The impacts from the literature are modified based upon two factors. First, the impact of V2I applications depends on the level of connected vehicle deployment. A V2I application will have a much smaller impact if few vehicles are capable of receiving and acting upon connected vehicle data than if the majority of vehicles have these capabilities. VBET incorporates a default penetration rate of CV communications, which can be adjusted in the "3.2. BCAPeneRate" worksheet. Second, the effectiveness or efficacy of V2I applications depends on the level of V2I adoption. The user can adjust how the efficacy of each application varies with the communication penetration rate in the "3.3. BCA Efficacy" worksheet.

To conduct a BCA, the user steps through the four worksheets (two in basic mode) described below. The user can see the detailed BCA calculations if "Show Entire Model" is selected on the VBET opening screen. Most users will choose not to view the detailed calculations.

3.1. Determining V2I application(s) impacts in steady state[1] ("3.1. BCAInputs")

This is the first of three input screens available for conducting a BCA. Inputs on this screen are required for VBET to calculate a BCA. This input screen is the only one shown if the basic model is selected. The other two input screens are shown in the **Advanced** mode.

The input screen initially loads with purple instruction boxes shown to help the user complete the required input data. These boxes disappear when the user clicks on them. The user instructions can be toggled on and off using a button on the navigation bar.

1. Basic Model Information

The *Basic Model Information* section allows the user to provide the general inputs necessary for conducting a BCA.

1. **Analysis Start Year** – Enter the year the analysis begins. All benefits and cost will be discounted to this year. The year selected should be the first year of V2I deployment or earlier.
2. **Analysis Period** – Provide the number of years (20 to 50) in the analysis period. This is the number of years for which VBET calculates user benefits.
3. **Real Discount Rate** – Enter the discount rate for the user benefits in real dollars. VBET uses a default discount rate of 7%. This rate typically ranges from 3% to 7%. A separate discount rate of 3% is used for the benefits of reducing CO_2 emissions.
4. **First year (for VMT and VHT baseline)** – Enter the first year for which baseline vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT) data are available. This year does not need to equal the analysis start year.
5. **Future year (for VMT and VHT projections)** – Enter a year for which future VMT and VHT projections are available. This year can be any year after the First year (for VMT and VHT baseline) (see Item 4). VMT and VHT values will be interpolated in the benefits calculations for years between First year (Item 4) and Future year (Item 5).
6. **Method for consolidating impacts for multiple applications** – Select from the dropdown list a method for combining the impacts of multiple V2I applications. VBET can use any of the following methods for combining impacts:
    - Minimum – use the smallest impact of the V2I applications included in the analysis
    - Maximum – use the largest impact of the V2I applications
    - Average – take the average impact of the V2I applications
    - Product – estimate the cumulative impacts of the V2I applications using multiplication (example: 10% reduction and 20% reduction would yield 0.90 x 0.80 = 0.72 benefits).

2. V2I Applications and Cost Data

VBET allows the user to consider the impact of a single V2I application or multiple applications (up to 15). The *V2I Applications and Cost Data* section provides input fields to specify the V2I applications to

[1] The VBET methodology assumes that V2I applications will not reach their full potential until all vehicles have CV communications. Steady state refers to a time when all vehicles have CV communications (i.e., 100% communication penetration) and the V2I applications have achieved their full efficacy (i.e., 100% efficacy). CV applications achieve their maximum benefits at "steady state."

include in the BCA, the year each application will be deployed, and the total lifecycle (i.e., capital, operating, maintenance, and replacement) costs:

1. **Select Application(s) to be included in the analysis** – Select V2I applications from the dropdown list. Each application should be entered on a separate row in the table.
2. **Deployment start year** – Enter the first year of V2I deployment for each application. Multiple applications may have different start years.
3. **Number of years of capital cost** – Enter the number over which the capital costs of V2I deployment should be allocated. If the value in this column is more than 1, the value in column Total cost including O&M cost (by program year): Initial capital cost (Year 0) (see Item 5) will be spread across multiple years. Individual applications may vary in the number of years of capital cost. VBET assumes that user benefits will not start for each application until the corresponding capital costs have been expended (i.e., infrastructure deployed).
4. **Total cost** – This column shows the total non-discounted costs for each application separately. This is a calculated field. The user should not make any changes to this column.
5. **Total cost including O&M cost (by program year)**: **Initial capital cost (Year 0)** – In this column the user specifies the capital cost for V2I infrastructure deployment. If Number of years of capital cost (Item 3) is greater than 1, the value in this column is spread across multiple years.
6. **Total cost including O&M cost (by program year): Years 1-30** – Enter costs by year for each application. Note that the AASHTO near-term V2I deployment LCCM tool provides only 20 years of lifecycle cost. Additional user will need to enter the last 10 years manually if the LCCM tool data are imported (see Item 8), because the LCCM tool calculates only 20 years of lifecycle cost data.
7. **Include any adjustment to apply to total costs** – Enter any adjustments to the V2I costs provided in the table. The last line of the table allows the user to make adjustments to the V2I costs. This feature is helpful if the user chooses to import cost data from the LCCM tool, because that tool does not take into account the overlapping costs of multiple V2I applications. However, subtracting duplicate costs for multiple applications can become complicated if the applications have differing construction start years (Item 2) and numbers of years of capital cost (Item 3). Overlapping costs should be entered as negative numbers in this row, so they are subtracted. Additional costs should be entered as positive numbers.
8. **Import Costs from V2I-LCC Tool button** – Click this button to import data directly from the AASHTO near-term V2I deployment LCCM tool. This simplifies the entry of cost data if the information is already available in an LCCM tool Excel file. Note that the LCCM tool needs to have been run and results saved before clicking on this button. After clicking the button, the user will be prompted to select an Excel file. The selected file must be of the supported format for this feature to work properly. A successful import will include the list of selected applications (Item 1) and the first 20 years of total cost by year for the first 20 years (Items 4 through 6) for the selected applications. The user should still enter the Construction year start (Item 2) and number of year of capital cost (Item 3) for each application.

3. *Travel Characteristics and Forecasts*

This section allows the user to enter travel characteristics and forecasts for the appropriate geographic level of analysis (e.g., spot location, corridor, or region). The user is expected to have this information available for the No Build from an outside model (e.g., travel demand model) or other planning methods. The data entered should be the total across the geographic area. V2I applications that impact different road types will need to be evaluated separately.

1. **Road type**[2] – Select a road type from the list. The options are "Urban Unrestricted", "Urban Restricted", "Rural Unrestricted" or "Rural Restricted." This selection is used in estimation of emissions benefits. If the geographic area includes multiple road types, this selection should indicate the most common type.
2. **First Year Baseline** – This section is used to enter VMT and VHT data for the First Year (Item 4 in *Basic Model Information* section).
    a. **Average annual daily vehicle-miles traveled (VMT per day)** – Enter VMT by mode (Automobile, Truck, and Transit) for No Build conditions in the First Year.
    b. **Average annual daily vehicle-hours traveled (VHT per day)** – Enter VHT by mode (Automobile, Truck, and Transit) for No Build conditions in the First Year. If VHT is not available, it can be calculated as VMT divided by average speed (in miles per hour).
3. **Future Year Baseline** – This section is used to enter VMT and VHT data for the Future Year (Item 5 in *Basic Model Information* section).
    a. **Average annual daily vehicle-miles traveled (VMT per day)** – Enter VMT by mode (Automobile, Truck, and Transit) for No Build conditions in the Future Year.
    b. **Average annual daily vehicle-hours traveled (VHT per day)** – Enter VHT by mode (Automobile, Truck, and Transit) for No Build conditions in the Future Year.
    c. **Growth Rates** – VBET automatically calculates the implied annual growth rate in VMT and VHT by mode between the First Year and the Future Year. The growth rates are presented in the table to the right of the First Year Baseline (Item 4).
4. **Stop VMT and VHT growth after the Future Year** – Select whether the VMT and VHT data should stay the same after the future forecast year (Item 5 in *Basic Model Information* section). If the user selects "Yes," the model uses the Future Year forecasts for subsequent years. If the user selects "No," the model extrapolates VMT and VHT data beyond the Future Year based on the growth from the First Year.
5. **Crash Data in First Year** – This section is used to enter crash data by severity.
    a. **Average number of annual crashes (crashes per year)** – Enter the number of crashes that occur in the study area by severity (Fatal, Injury, and PDO) during the First Year (Item 4 in *Basic Model Information* section).

[2] The Road Type selection is used in estimation of emissions benefits. According to the users guide for the Federal Motor Vehicle Emission Simulator (MOVES) emissions model, (2010b, page 30), https://www3.epa.gov/otaq/models/moves/documents/420b12001b.pdf), "the default database has Road Types that represent urban and rural driving on roads with restricted and unrestricted vehicle access. Restricted access Road Types are usually used to model freeways and interstates; ramps are considered part of restricted access Road Types."

b. **Annual percent change in crash rate (percent per year)** – Enter as a percentage the expected annual change in the crash rate by severity (Fatal, Injury, and PDO). Most users will enter 0% change. If the study area has been experiencing a general improvement in crash rates, then the percent change should be entered as a negative. Note that these entries refer to the crash rate (crashes per VMT) rather than the number of crashes.

3.2. Determining CV-equipped vehicle fleet penetration rate ("3.2. BCAPeneRate")

This is the second of three input screens available for conducting a BCA. Inputs on this screen are required for VBET to calculate a BCA. This input screen allows the user to adjust the CV communication penetration rate. VBET provides default penetration rates for each V2I application, depending on the communication technology. This screen appears only in the **Advanced** mode.

1. Default Fleet Communication Rates

This section displays four default fleet penetration rates for different types of CV communication: Dedicated Short Range Communication (DSRC), DSCR^2, Cell, and 100%. "DSRC" is used for V2I applications that rely on DSRC. "DSCR^2" is used for V2I applications that rely on information from other vehicles on the roadway. The DSCR^2 rate is obtained from the National Highway Traffic Safety Administration (NHTSA) vehicle-to-vehicle (V2V) readiness report,[3] where it represents the V2V communication equipment deployment in new vehicles. The DSRC rate is the square root of this rate. "Cell" is used for V2I applications that rely on cellular communication. VBET assumes that the cellular penetration rate for V2I applications is the same as DSRC. "100%" penetration is used for V2I applications that involve transit or commercial fleets. V2I communication penetration rates are provided for each year from 2020 to 2080.

2. Modified Fleet Communication Rates

This section allows the user to modify the V2I communication penetration rates used for the BCA. Column G of the table lists the applications selected on the previous input screen (*V2I Applications and Cost Data* table), while Column I shows the default penetration rate for each application. If the user wishes to modify a penetration rate, this is indicated by selecting "Use Modified" from the dropdown list in Column H. "Use Recommended" will use the default penetration rate.

When the "Use Modified" option is selected for an application, the user must provide the expected penetration rates for every 5 years into the future, so VBET can construct the overall user-defined penetration curve. The cells that should contain the user input values will be highlighted in light-green – see Columns J, O, T, Y, AD, AI, AN, AS, and AX (for every fifth year between 2020 and 2060). VBET will fill in the intervening values by interpolating linearly, using each neighboring pair of values provided. The values for the years 2061 through 2080 will be equal to the value in 2060.

The table that follows the *Modified Fleet Communication Rates* table shows the final penetration rates that will be used in the BCA. These rates are also shown in a graph after the table.

[3] 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.

3.3. Determining the efficacy adjustment factor ("3.3. BCAEfficacy")

This is the third of three input screens available for conducting a BCA. This input screen allows the user to review the efficacy of each application at different CV communication penetration rates. VBET asks the user to define four different penetration rates, which are used to define an approximate S-curve. This screen appears only in the **Advanced** mode.

VBET provides default values for efficacy adjustment factors. Since no information on efficacy was available in the existing V2I literature, these values have been set so the model linearly interpolates between 0% and 100%. This corresponds to the model assuming 0% efficacy at 0% communication penetration, 50% efficacy at 50% communication penetration, and 100% efficacy at 100% communication penetration. These default values can be adjusted as new literature comes available. The default values can be found in the "ImpactValuesLookup" worksheet, which is displayed calculations if "Show Entire Model" is selected on the VBET opening screen.

1. Application Efficacy

This table shows the default efficiency rates imbedded in the tool. None of the cells in the table are user inputs. The user may review the efficacy rates by examining columns L through AF or by looking at the graph that appears below the table.

Each efficacy curve is defined by four values:

1. **Efficacy at 0% Penetration –** This value defines a point on axis Y (Efficacy) when X (Penetration or Communication rate) is at 0%. The efficacy of a V2I application is assumed to remain at this efficacy until the communication-equipped vehicles reaches the take-off penetration rate.
2. **Take-off Penetration –** This value defines a point on axis X (Penetration rate) when efficacy starts to grow linearly. This is the beginning of the steep portion of the S-curve.
3. **Saturation Penetration –** This value defines a point on axis X (Penetration rate) when the growth of efficacy stops (reaches its plateau). This is the end of the steep portion of the S-curve.
4. **Efficacy at 100% Penetration –** This value defines a point on axis Y (Efficacy rate) when the maximum efficacy is achieved.

3.4. BCA Results (3.4. BCAResults)

This worksheet provides the user with the results of the BCA. VBET itemizes user benefits according to several categories:

- Travel time for automobiles, trucks, and transit;
- Safety;
- Vehicle operating costs;
    - Fuel-related costs for gasoline and diesel fuel;
    - Other operating costs for automobiles and trucks; and
- Emissions in terms of nitrogen oxides (NO_x), carbon dioxide (CO_2), volatile organic compounds (VOC), fine particulate matter (PM), and sulfur dioxide (SO_2).

The itemized benefits represent total benefits per category over the analysis period (in years) chosen on the "3.1. BCAInputs" worksheet. A bar graph to the right of the benefits table shows the relative contribution of each benefits category to the overall results. The results page also shows the total discounted[4] benefits across categories. These can be compared to the total discounted costs of V2I deployment, which are also displayed.

VBET provides four summary cost-effectiveness measures:

- Benefit-cost ratio, which is the total discounted benefits divided by total discounted costs;
- Net present value, which is the total discounted benefits minus total discounted costs;
- Payback year, which is the year when cumulative benefits equal or exceed the deployment costs; and
- Internal rate of return, which shows the interest rate that the total deployment costs would need to achieve to equal the total benefits produced.

VBET lists the V2I applications included in the analysis at the end of the page. The steady-state impacts on Travel Time, Vehicle Operating Costs, Number of Crashes, and Emissions reported in the literature review are also presented. This table appears under the main results table if at least one CV Application is selected in "3.1. BCAInputs" worksheet. In addition, the user can find the individual percent improvements for other applications in the "ImpactValuesLookup" worksheet, which is displayed if "Show Entire Model" is selected on the VBET opening screen.

Economic Impact Analysis (EIA)

VBET allows the user to estimate the potential impacts of V2I user benefits on the state or regional economy using an input-output methodology. While the preferred approach is to estimate economic impacts using a regionally specific economic model, VBET provides a simple approach for high-level analysis. The accompanying desk reference describes regional economic models in more detail.

VBET estimates economic impacts using national input-output matrices from the 2012 Transportation Satellite Accounts (TSA). These accounts have been by application developed by application by the Bureau of Economic Analysis (BEA) and the Bureau of Transportation Statistics (BTS) and are updated every few years. VBET provides a method to scale national impacts to a state or metropolitan area. However, the analysis is approximate since smaller economies (i.e., states and metropolitan areas) are more likely to import goods and services than is the national economy.

The user must conduct a BCA before estimating the economic impacts. VBET uses the results of the BCA user benefits as inputs to the EIA. Only benefits that are "on-the-clock" (e.g., business travelers and freight travel) are included. This information is pulled into the EIA analysis automatically after the BCA is completed.

[4] In a BCA, future benefits and cost are discounted to reflect the fact that a dollar today is worth more than a dollar a year from now, even when inflation is taken into account. Discounting puts present and future benefits and costs into a common metric called present value.

The user may want to use other planning methods (e.g., gravity models, and integrated land-use and transportation models) to estimate economic development impacts. These methods are described in the desk reference.

3.5. Economic Impact Analysis Assumptions ("3.5. EIAInputs")

This worksheet allows the user to provide inputs for the Economic Impact Analysis model. For most of the required inputs, the user will use the default values provided by the tool. However, a few inputs, such as defining the analysis area are required.

1. Study Area Definition

This table allows the user to select the appropriate geography and input-output data for the EIA.

1. **Select Area Type –** Select the geographic area for estimating the economic impacts by selecting "State" or "Metropolitan Area" from the dropdown list.
2. **Select State –** Select the correct state from the dropdown list. The state should be chosen even if the economic impact analysis is at the metropolitan level. If "United States" is chosen for a metropolitan level analysis, the full list of metropolitan areas will be provided in Step 3.
3. **Select Metropolitan Area –** This option applies only when "Metropolitan Area" is chosen in Select Area Type (Item 1). Select a metropolitan area from the dropdown list that includes only those metropolitan areas located in the state selected in Select State (Item 2). The dropdown list includes all metropolitan areas available if "United States" is selected in Select State (Item 2).
4. **Use MSA Data as is or State Distribution of MSA Totals –** This option applies only when "Metropolitan Area" is selected in Select Area Type (Item 1). For some metropolitan areas, the regional data is suppressed for industries with few employees (for anonymity purposes), thus eliminating industries from the industry mix. The user may chose to use the state mix of industries, which is less likely to be affected by data suppression. To use the distribution of employment at the state level, select "State Distribution."

2. Transportation Industries Directly Affected by V2I Deployment

This table allows the user to select the types of transportation that will be impacted by V2I deployments in terms of for-hire/in-house transportation and by mode. For-hire transportation refers to industries that provide transportation services to other industries. Examples of these industries include trucking and freight railroads. In-house transportation refers to transportation services that occur within the operations of another industry. For example, a forest products firm may operate its own logging trucks rather than hiring a trucking company.

VBET has the following two industries selected by default, since V2I is expected to impact highway travel:

- For-hire truck transportation
- In-house truck transportation.

Generally, the user will not change these selections, but it may make sense to select other transportation industries for certain V2I deployments. For example, V2I deployment along an airport access corridor may affect air cargo. In this case, the user may also select for-hire air transportation and in-house air transportation.

3. Annual Change in Generalized Transportation Costs

This section allows the user to check and adjust the size of the transportation cost savings due to V2I deployment that will generate economic impacts.

1. **Change in Business Transportation Costs, $ 2012 Million –** Enter the change in business-related transportation costs associated with V2I deployment in millions of 2012 dollars. A reduction in costs should be entered as a negative number. By default, VBET enters the average travel time benefits for trucks and on-the-clock (business-related) automobiles in this cell. As a result, the user should make sure to complete the BCA as part of the economic analysis. However, the user may chose to enter another value (e.g., previously calculated benefits) in this box. The formula will be updated when the **Reset Inputs** button is pressed in the "3. ConductAnalysis" worksheet.
2. **Percent of Through-Traffic in Total Traffic used for Estimation of Business Transportation Cost Savings, % –** Enter the percent of total traffic that through traffic comprises. This percentage will not be included in the EIA. VBET includes an assumption that the economic impacts associated with through traffic accrue outside the study area.

4. Elasticity of Industry Output w.r.t. Changes in Production Costs by Sector

This section allows the user to identify the sensitivity of different industry sectors to savings in production costs. In economic terms, this is called the "elasticity of industry output with respect to (w.r.t.) production cost changes." VBET uses a default elasticity of -1 for most industry sectors. This means that a $1 saved in production costs increases industry output by $1. In the absence of better data, this is a standard assumption for transportation EIA. VBET uses a default elasticity of 0 for government, which means that changes in user benefits do not change the size of government. The user can change the elasticities, but this will be rare. Typically, the default elasticities will be used.

5. Economic Multipliers

This section allows the user to select the input-output multipliers used in the EIA. Economic multipliers are values by which an initial investment into an industry is multiplied to estimate direct, indirect, and induced effects. This tool uses Type I multipliers (the ones that do not include induced effects). Generally, the user will not make changes to this section.

1. **Select multipliers used in calculations** – By default, VBET assumes that the "National Estimates" from the Transportation Satellite Accounts (TSA) built into the model will be used. The user may select "User-Defined" if customized input-output multipliers are available. Users who are not familiar with these terms should leave the "National Estimates" default unchanged. If "User-Defined" is selected, the multipliers should be specified by the user in Item 2.
2. **Enter Type I Multipliers below –** If the user selects "User-Defined" in Item 1 because multipliers specific to the study area are available, the user should enter these multipliers in this table. The

entries should be Type I (i.e., direct plus indirect) multipliers for each industry sector. Users who are not familiar with these terms should select "National Estimates" in Item 1. The entries in these boxes are not used if "National Estimates" are selected.

3.6. Economic Impact Analysis Results ("3.6. EIAResults")

This worksheet provides the user with the results of the EIA.

1. Economic Profile of Study Area in Base Year

This section provides the user with a brief economic profile of the study area selected for the EIA (see *Study Area Definition* on the "3.5. EIAInputs" worksheet). The data reported in this section is built into VBET and comes from the Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA) for 2012. This year was chosen for consistency with the input-output multipliers. The worksheets with the raw data are available if "Show Entire Model" is selected on the VBET opening screen.

The economic profile includes the following information:

1. **Total Employment in 2012**
2. **Employee Compensation, in 2012 dollars**
3. **Total Value Added / GDP, in 2012 dollars**
4. **Output (Calculated), in 2012 dollars**

2. Annual Economic Impacts of V2I Deployments

This section summarizes the economic impacts of the V2I deployment for the user. Direct impacts are the impacts that occur for specific industries without taking into account purchases from other industries (indirect impacts). The total impacts include the direct and indirect impacts.

The first table lists the direct impacts summarized in terms of:

1. **Direct Output Impact, Million 2012 $**
2. **As Percent of Baseline Output**
3. **Direct Employment Impact, Jobs**
4. **Direct Earning Impact, Million 2012 $**

The second table lists the total impacts summarized in terms of:

1. **Total Output Impact, Million 2012 $**
2. **Total Value Added Impact Million 2012 $**
3. **Total Employment Impact, Jobs**
4. **Total Earning Impact, Million 2012 $**

All estimates are in 2012 dollars.

Capability 4: Get Help ("4. ModelInstructions")

This worksheet provides the user with an overview of VBET and step-by-step instructions on how to use the tool. Additional information about the V2I literature review and VBET can be found in the accompanying desk reference.

BCA Model Parameters ("5. BCAParameters")

This worksheet shows the default parameters included in VBET for BCA analysis. These parameters are consistent with Federal guidance and other Federal BCA tools such as TOPS_BC. Comments provide information on the source of each model parameter. The user can update any of the model parameters by typing in new values and the BCA results will be updated immediately. This feature is useful for a user wanting to use local BCA parameters. The parameters worksheet is visible only in the **Advanced** mode.

The model includes defaults for the following parameters:

1. *General Parameters*
    a. Year of Dollars Displayed
        i. Year of Dollar Display
        ii. Inflation Rate
    b. Annualization Factor
        i. Number of Periods per Year
    c. Net Present Value Calculation
        i. Time Horizon (Years)
    d. Traffic Mix
        i. Percentage "On-the-Clock" Travel Purpose (Autos)
        ii. Average Auto Occupancy
        iii. Average Truck Occupancy
        iv. Average Transit Occupancy
    e. Discount Rate
        i. Discount Rate
        ii. Discount Rate (for CO_2 emissions only)

2. *Benefit Valuations*
    a. Travel Time (per hour)
        i. "On the Clock" Travel Time
        ii. Other Auto Travel Time
        iii. Truck Travel Time
        iv. Annual growth in real income and value of time
    b. Crashes (per occurrence)
        i. Fatality

ii. Injury
iii. Property Damage Only (PDO)

c. Average Auto Maintenance Costs
    i. Auto Tire Cost
    ii. Auto Maintenance Cost
    iii. Auto Depreciable Value
    iv. Oil Price
d. Average Truck Maintenance Costs
    i. Truck Tire Cost
    ii. Truck Maintenance Cost
    iii. Truck Depreciable Value
    iv. Oil Price
e. Unit Conversions
    i. Kilograms per Short Ton (US)
    ii. Kilograms per Metric Ton
f. Emission Cost (per ton)
    i. Nitrogen Oxides (NO_x)
    ii. Volatile Organic Compounds (VOC)
    iii. Fine Particulate Matter (PM)
    iv. Sulfur Dioxide (SO_2)
    v. Carbon Dioxide (CO_2), for emissions occurring in 2013
g. Annual Social Cost of Carbon Values: 2010-2050 (in 2011 dollars)
h. Fuel Use
    i. Per Gallon (Excluding Taxes)
i. Non-fuel Operating Costs (per VMT)
    i. Auto
    ii. Truck
j. Noise (per VMT)
    i. Auto
    ii. Truck

3. Speed/Flow Relationships

a. Freeway Speed Factor by V/C ratio
b. Arterial Speed Factor by V/C ratio
c. Ramp Speed Factor by V/C ratio

4. Crash Rates (per Million VMT)

a. Freeway Fatality Crash Rate by V/C ratio
    i. Auto
    ii. Truck
b. Freeway Injury Crash Rate by V/C ratio
    i. Auto

ii. Truck

c. Freeway PDO Crash Rate by V/C ratio
   i. Auto
   ii. Truck

d. Arterial Fatality Crash Rate by V/C ratio
   i. Auto
   ii. Truck

e. Arterial Injury Crash Rate by V/C ratio
   i. Auto
   ii. Truck

f. Arterial PDO Crash Rate by V/C ratio
   i. Auto
   ii. Truck

5. Fuel Economy (MPG)

a. Fuel Consumption
   i. Autos
   ii. Trucks

b. Fuel Cost
   i. Diesel Bus Fuel Efficiency
   ii. Annual Growth in Bus Fuel Efficiency

Summary of Studies ("6.1. StudiesSummary")

This worksheet shows the detailed study data reported in *Capability 1: Investigate Potential Impact of V2I Applications*. The user may update the data shown on the worksheet as more research becomes available. The worksheet provides instructions on how to add data. The Summary of Studies worksheet is visible only in the **Advanced** mode.

List of Studies ("6.2. StudiesList")

This worksheet lists research studies that provide the impacts shown in the "Summary of Studies" worksheet. The user should update the list as new studies are added to the VBET database. The List of Studies worksheet is visible only in the **Advanced** mode.

Contact Information

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