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USER'S GUIDE FOR PET: PROJECT EVALUATION TOOLKIT

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TxDOT Project 0-6487: Development of a Performance Measurement Based Methodology to Objectively Compare Operational Improvements with Capacity Additions

TxDOT Project 5-6235: Implementation of Project Evaluation Toolkit for Abstracted Networks

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User's Guide for PET: Project Evaluation Toolkit

A Sketch-Planning Toolkit for Evaluating Highway Transportation Projects

Version 2.0

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i.   Introduction

Transportation planning involves evaluating the congestion, safety, emissions, and other impacts of large-scale network improvements and policy implementations. This document is a **User's Guide** for the **Project Evaluation Toolkit** (PET), a sketch planning toolkit developed for evaluating a variety of strategic- and operational-level **transportation network improvements**. PET's development was sponsored by Texas Department of Transportation (TxDOT) under TxDOT research project 0-6235 (titled "Sketch Planning Techniques to Assess Regional Air Quality Impacts of Congestion Mitigation Strategies") and its associated implementation project (5-6235), along with research project 0-6487 (titled "Development of a Performance Measurement Based Methodology to Objectively Compare Operational Improvements with Capacity Additions"). This Guide provides users with a detailed description of PET's design and specification and a technical guidance in using PET for project evaluation and comparison.

PET is a **spreadsheet-based application** that offer users a familiar and powerful data manipulation interface for evaluation of abstracted networks' improvements and modifications. PET **includes a travel demand estimation module** implemented as a set of external C++ programs for destination, mode, time of day, and route choices, across multiple user classes. Other functional modules, including economic analysis, environmental impact evaluation, safety evaluation, sensitivity analysis, and budget allocation, are implemented in Microsoft Excel spreadsheets. PET can be used with or without its travel demand model (TDM) component. Users with existing TDM outputs can rely on PET's back-end programming for estimates of traveler welfare, emissions, crashes, and travel-time reliability used to generate benefit-cost ratios, internal rates of return, and other metrics that characterize projects on any network, whether coarse or detailed, small or large. In other words, PET can play a vital role in almost any project evaluation setting.

PET requires few inputs to run, but accommodates many optional parameters. Required inputs include only project cost estimates and basic network information (e.g., nodes, directional/one-way links, link capacities, and observed or estimated link volumes/flows in the initial year) for a base case, and up to three alternative networks, with the option to manipulate many other default parameters, such as time of day settings, values of travel times (for each of five user classes), mode alternatives, and others. PET **outputs** include **link flows** by time of day and user time, **traveler welfare** (calculated using the rule-of-half between all origin-destination pairs, by user class), travel time **reliability** (for each link), fatal, injurious, and property damage **crash counts** on each link, **emissions** for 14 species, **benefit-cost** ratios, internal rates of return (**IRRs**), and other performance metrics (from agency and social perspectives), as well as plots of all major outputs (relative to base case outputs) over time (with interpolations for years between initial and design years).

PET estimates vehicle emissions using an extensive spreadsheet database of the Environmental Protection Agency (EPA)'s MOVES 2010a emissions rates for 14 species (including 5 air toxins). Traffic accident losses and safety implications are estimated using *Highway Safety Manual* (AASHTO 2010) equations, which are based on crash rates developed using US crash data.

In summary, PET is a quick-response, self-contained toolkit designed for evaluating transportation projects on the sketch-planning level or for detailed networks whose trip tables, link flows, and travel time and cost skims have already been developed using a more detailed planning model. It enables transportation planners to comprehensively yet quickly anticipate and analyze the various impacts of diverse network improvement strategies.

ii.   Guide Layout

The user manual is broken into two main sections: Part 1, **Using the Toolkit** and Part 2, **Understanding the Toolkit**. Part 1 takes users through a step-by-step process showing how to load PET, develop scenarios, run the travel demand model, and understand the resulting outputs. Part 2 goes deeper into the background behind the methodologies used to develop the PET framework and many of the parameters.

iii.   PET Version 2.0 and Subsequent Releases

PET 2.0 was released in summer 2012, and it includes many updates to the Toolkit's trip table calculation process, along with the addition of transit-specific components, origin- and destination-focused trip costs, multi-criteria analysis, and a network visualization module. PET 2.0 also enjoys updated emissions and crash estimation procedures (to rely on MOVES and the *Highway Safety Manual*'s latest equations). All material in this Guide refers to the updated 2.0 version of PET.

PART 1: USING THE TOOLKIT

This section details how users can use PET to estimate potential impacts of various project scenarios. The section gives detailed accountings of how users load PET onto their computers, build transportation networks, develop and run project scenarios, and evaluate the Toolkit outputs. While all information required to conduct these processes is contained within Part 1 of this User Guide, users may wish to refer to Part 2 and various appendices while developing projects to more fully understand how the Toolkit works, obtain details on developing specific project types, and discover the basis for PET's parameter defaults.

Chapter 1. System Requirements and Installation

The Project Evaluation Toolkit (PET) is a software package that runs on Microsoft Windows. The recommended operating environment is Windows Vista (all editions), Windows 7 (all editions), or a later version. The PET computer files include two executable files and a Microsoft Excel file with VBA macros embedded. Two folders are also included for sensitivity testing and analysis. Microsoft Excel must be installed on the computer for running PET. For full compatibility, Microsoft Excel 2007 or its later versions are recommended.

PET operation has no minimum hardware requirement; however, the computer hardware's specification should satisfy the basic need for running Windows 7 or a later version and Microsoft Excel 2007, Excel 2010, or a later version. For these hardware requirements, the user should refer to the technical specifications suggested by the following websites:

- Microsoft Windows 7: http://windows.microsoft.com/en-US/windows7/products/system-requirements
- Microsoft Excel 2007: http://www.microsoft.com/officebusiness/products/technical-requirements.aspx
- Microsoft Excel 2010: http://office.microsoft.com/en-us/products/microsoft-office-2010-system-requirements-HA101810407.aspx

The PET package includes eight computer files (available from the provided CD/DVD-ROM):

- **sketch_toolkit.xlsm** (Microsoft Excel file with VBA macros embedded)
- **toolkit_upload_file.xls** (Microsoft Excel file)
- **tdm_matrix.exe** (Executable file)
- **tdm_flow.exe** (Executable file)
- **STInput** (Empty file folder)
- **STOutput** (Empty file folder)
- **budget_allocation_module.xls**

PET is a set of ready-to-run computer programs. No installation is required prior to running PET. Because it writes input/output data and parameter files, PET cannot run on a read-only drive. The user needs to copy all computer files from the provided CD/DVD-ROM into a single folder on the computer's hard drive. Loading PET can be accomplished by using Microsoft Excel to open *sketch_toolkit.xlsm* and setting the Excel as "macro-enabled," which allows the user to enter PET's interface and access all necessary functions.

To enable macros in Microsoft Excel, the user needs to open the macro security settings dialog box and select ***Enable all macros***. The dialog box can be opened from the *Developer* tab in the ribbon. Alternatively, the user can click *Options* under the *File* menu (or under the *Microsoft Office button* in Microsoft Excel 2007) then go to the *Trust Center*. Click the *Trust Center Settings...* button, then select the ***Enable all macros*** setting. Press OK to save the new settings and return to PET.

Chapter 2. Loading Networks, Setting Parameters, and Developing a Base Case Scenario

This section details how users can understand PET's input system, navigate PET, use the Toolkit Upload File, develop and load transportation networks, and set parameter values. Readers should be able to develop a base case scenario with all required settings by the end of this section.

2.1 Color Coding Scheme

It is crucial that users understand PET's color coding scheme before developing scenarios and modifying parameters. Five colors are used: white, green, blue, pink, and yellow, all of which carry specific meanings as follows.

White: *Labels* and *Toolkit Estimates* based on internal formulas, parameters, and user inputs.

Green: *Parameter Values* with default settings, for system-wide conditions and assumptions.

Blue: *User Inputs* for project-specific settings that should be entered by the analyst.

Pink: *Travel Demand Model Outputs* for link-level traffic volumes, traveler welfare estimates, and sensitivity testing results.

Yellow: *Key Results* generated by PET.

Note that blue inputs cells *should* be modified by the analyst, green input cells *may* be modified by the analyst or left as default, and white, pink, and yellow cells *should not* be modified by the analyst. In particular, replacing the formula in a white or yellow cell with a singular value is dangerous. If the analyst forgets to immediately change the value back, the change could likely become permanent as finding a single formula alteration may be difficult among the thousands of formulas contained within PET. To avoid this, all white and yellow cells are protected by default. However, the user may toggle cell protection in Excel through the File → Info tab or Review → Unprotect Sheet button, using the case-sensitive password "PET."

2.2 Toolkit Navigation

Understanding PET's layout and simple navigation system is highly useful before developing a network, setting parameters, and testing alternative scenarios. PET has over 80 worksheets, so a navigation panel is provided to facilitate analysis and project development. In order to access the navigation panel, simply press the "**Go To Navigation Panel**" button in the upper left corner of any sheet, as shown in Figure 2.1:

Figure 2.1: Accessing the Navigation Panel[1]

This will instantly take the user to the navigation panel that should look like Figure 2.2:

Figure 2.2: Navigation Panel (not all navigation buttons shown)

The user will be able to access any PET sheet by pressing the corresponding navigation button. The analyst may also access a description of the sheet by dragging the mouse over the question mark located next to each navigation button.

The Main Toolkit File has nine general categories of sheets:

1. **General Project Information** – Output results, information for using PET

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[1] Note: Almost all screen shots in this Guide show only a partial view of the screen. Up to hundreds of rows and/or columns are not shown due to space and visibility limitations.

2. **Key Project Inputs** – Information required for scenario parameters and network characteristics

3. **Optional Project Inputs** – Information that may be entered for conducting more detailed analyses or for special types of projects

4. **Project Summaries** – Results for overall scenario impacts, as well as impacts by category

5. **Individual Scenario Volume Outputs** – Estimated link-level traffic volumes, reliability and speeds for each scenario, initial and design year

6. **Individual Scenario Link Crashes** – Estimated link-level number of crashes for each scenario, initial and design year

7. **Individual Scenario Intersection Crashes** – Estimated intersection-level number of crashes for each scenario, initial and design year

8. **Individual Scenario Emissions Estimates** – Estimated link-level emissions quantities for each scenario, initial and design year

9. **Emissions Tables, Fleet Info and Fuel Economy** – Lookup files for emissions and fuel use estimation

2.3 The Toolkit Upload File

Users have two ways to enter data into PET: through the **Main Toolkit File** (sketch_toolkit.xlsm) or through the **Toolkit Upload File** (toolkit_upload_file.xls). Entering data into PET through the Main Toolkit File may be conducted by editing green or blue cells to change network, parameter, or other input information. This works fine for small edits and developing new scenarios, but can be laborious if a significant amount of input data is required (for example, developing a new network from scratch). The Main Toolkit File contains numerous formulas, and only a small processing delay occurs each time a new value is entered.

In order to address this issue and provide a **convenient location for all inputs**, the analyst may opt to use the Toolkit Upload File. The Toolkit Upload File contains seven sheets: *Required Link Information*, *Optional Link Information*, *Tolling Information*, *Time of Day Information*, *Parameter Information*, *Travel Growth Rates*, and *Link Sources*.

- The first three sheets (*Required Link Information*, *Optional Link Information*, and *Tolling Information*) contain link-specific data regarding the existing base case scenario.

- The user is encouraged to **input references** for each data category in the *Link Sources* sheet.

- The remaining three sheets (*Time of Day Information*, *Parameter Information*, and *Travel Growth Rates*) contain user inputs that impact all scenarios and include data reference cells for analysts to note sources used when changing default parameters.

Figure 2.3 shows the *Required Link Information* sheet as an example.

Figure 2.3: Required Link Information Sheet of the Toolkit Upload File

Once the user has finished inputting all desired data into the Toolkit Upload File, the file must be closed and the Main Toolkit File opened (sketch_toolkit.xlsm). To upload data from the Toolkit Upload File, navigate to the "Project Evaluation Toolkit Home" sheet. In the lower left corner is a button labeled "Import Transportation Data" as well as user input cells for importing data from the Toolkit Upload File, as shown in Figure 2.4:

Figure 2.4: Controls for Uploading Transportation Data

Enter a "1" for every sheet in the Toolkit Upload File that the user wishes to import. Be aware that any imported data will write over existing data currently in the Main Toolkit File. Ensure that the Toolkit Upload File is in the same directory as the Main Toolkit File and that the file name in the Data Upload Procedure box is spelled exactly the same as the Toolkit Upload File (including the exact file extension [e.g., ".xlsx" or ".xls"]). When ready to proceed, press the "**Import Transportation Data**" button to load data from the Toolkit Upload File to the Main Toolkit File.

2.4 Parameters

Numerous parameters may be edited in either the *Summary Input Information* sheet of the Main Toolkit File or the Toolkit Upload File. The six general parameter categories include *General Project Information*; *Capacity and Reliability*; *Operating Costs*, *User Groups and Modes*; *Motor Vehicle Safety Parameters*; *Temperature, Emissions, and Fuel Use*; and *Sensitivity Testing*. Clicking on the "**Summary Input Information**" navigation button should bring up the *General Project Information* sheet shown in Figure 2.5:

Figure 2.5: Parameter Input Information

The **General Project Information** parameters contain basic inputs, including the number of scenarios, scenario names, initial years for construction and operation, traffic growth rate, project design life and discount rate. It is highly recommended that the analyst review each of these values as they will likely vary from one analysis to the next and will strongly influence project outcomes. Also, if the analyst wishes to use PET's travel estimation procedure, be sure that "Use External TDM Outputs" is set to 0. If using PET's back-end capabilities to read in external regional travel demand model results, set this parameter to 1.

The **Capacity and Reliability** parameters include free-flow speeds, a heavy vehicle-to-passenger car equivalency factor (for use in V/C estimates), and parameters that impact estimated speeds and reliability. The analyst may want to adjust free-flow speeds if typical local settings are different than PET defaults. Other parameters may also be adjusted at the user's discretion.

The **Operating Costs**, **User Groups and Modes** parameters include values of time and reliability for various population groups (as well as population group proportions), average vehicle occupancy for transportation modes, modal operating costs, and probabilities that given travelers of various types will select certain modes. Note that the four default user types are heavy truck drivers, travelers with work-related purposes (non-heavy truck), commuters, and travelers with

other purposes. These values may be modified to reflect local conditions if the analyst has more detailed information.

The **Motor Vehicle Safety Parameters** influence the estimated value of crashes, distribution of crash severity, and frequency of crashes. Current crash valuations are based on federal (USDOT) guidance, including the statistical value of life (Trottenberg and Rivkin 2011) as well as fractions of the statistical value of life for injuries at various levels of severity. Analysts may opt to update crash values, report but not monetize crashes, or adjust them to reflect non-economic components. Also, the analyst may choose to adjust the predicted crash severity distribution based on more recent or local data. This Guide recommends that the analyst not adjust the safety performance function (SPF) parameters or land use adjustment factors. However, the analyst may change the Local Crash Calibration Factor value if crash rates in the area are higher or lower than the statewide average.

The **Temperature, Emissions and Fuel Use** parameters are used for estimating emissions, emissions costs, and fuel usage. The user should select the location corresponding to closest climate region and season for analysis (either summer or winter). Three climate locations are available (Dallas, Waco, and Houston) representing slight variations in average temperature and humidity. By default, emissions are not monetized, though the user may opt to use these costs and assign dollar values to various emissions species. Some default costs per ton are provided, based on USDOT guidelines (Trottenberg and Rivkin 2011). The fuel use-speed relationship should not be altered unless new data is available.

The **Sensitivity Testing** parameters may be adjusted to conduct sensitivity testing trials. Up to 21 different parameters may be varied, using a lognormal distribution. To enable sensitivity testing, enter an integer value greater than 1 in the *# of Sensitivity Testing Trials* input cell and ensure that at least one parameter has a coefficient of variation greater than 0. Users should be aware that sensitivity testing trials will take substantially longer to run than ordinary travel demand model runs. Also, the sensitivity testing will report traffic volumes for up to 10 traffic links. These must be set before running the travel demand model and may be set by clicking the "**Sensitivity Testing**" navigation button then changing the **Link Number** parameter inputs in the "Initial Year Traffic Links – AADT" analysis row, as shown in Figure 2.6.

Initial Year Traffic Links - AADT	Link Number:		145	Link Number:		146
	Average	+1 S.D.	-1 S.D.	Average	+1 S.D.	-1 S.D.
Base Case (No Build)	21296	25912	16680	22033	27020	17046
290 Freeway Upgrade	21510	24271	18748	21608	24747	18469
290 Tolled Freeway	17031	22389	11673	17058	22263	11853
290 Tolling by Vehicle Class	17920	23337	12503	17903	23216	12591

Figure 2.6: Setting Analysis Links for Sensitivity Testing

Two additional parameters are addressed here: *Operational* and *Travel Demand Estimation Procedure*.

The **Operational Parameters** apply solely for operational analyses (see Sections 3.6 and 10.6). Here, users should specify project life and incident growth rate, and may change detailed values such as average vehicle occupancy, average value of travel time (VOTT), average incident

duration and frequency for specific times of day. Vehicle occupancy and VOTT specified here will apply only to operational studies and will not override values set elsewhere.

The ***Travel Demand Estimation Procedure*** has a single parameter: maximum allowable average link flow error. This parameter governs how closely modeled traffic flows (calculated in the travel demand estimation procedure) match observed traffic flows (entered by the user) when estimating a trip table between all origins and destinations. Users should be cautioned that if this parameter is set too low, the majority of origin-destination flows will simply be between adjacent links.

For a full list of parameters, default values, sources and descriptions, see Appendix B.3.

2.5 Traffic Distribution by Time of Day

Once the parameters have been reviewed, the next step is to ensure that each link's within-day traffic patterns rise and fall to reflect traffic variations. To accomplish this, access the Time of Day (TOD) Splits sheet by clicking on the "**TOD Splits**" navigation button.

Links are directed (one way) in PET, and the user may set up to five **TOD period settings**, to represent, for example, the AM peak, midday, PM peak, evening, and off-peak periods, as shown in Figure 2.7. This is accomplished by setting the start times for each of the five TOD periods. Once this is completed, the analyst may enter up to twelve **TOD traffic distribution references** or "**stations**." Essentially, different road types or different locations may experience very different TOD splits in traffic (AM versus PM flow splits on a link headed into the downtown, for example), so each link can be tied to a different distribution. The duration of each TOD period should be chosen such that traffic volumes and patterns are relatively uniform or stationary within each TOD period, as much as possible.

The term "station" comes from the notion of an automatic traffic recorder (ATR) station. For example, recreationally used roads on a region's periphery may have high off-peak splits— outbound in the AM and returning in the PM. Links leading to a region's employment-rich central business district may have very high peak splits: the AM traffic heading inward (e.g., southbound) might exceed the PM traffic in that same direction/on that same link, but better match the adjacent (northbound) directed link's PM flow, as commuters return home in the evening. Directionality is important for many routes, and PET allows analysts to reflect such TOD imbalances from one link and one direction of one corridor to the next. Up to 12 such traffic split distributions or stations may be used, each with up to five TOD shares (i.e., proportions of daily traffic). Of course, total traffic volume at each station across all TOD periods must sum to 1.0. Information about traffic distribution by TOD may best be obtained from the region's permanent ATR data.

Figure 2.7: Time of Day Splits

Demand elasticity for each TOD period may also be set in this sheet, though this Guide recommends that the same value of elasticity be used for all TOD periods. The TOD scale parameter may be adjusted on this sheet, though any adjustments should be conducted with care and only by analysts with substantial understandings of incremental logit model operation.

2.6 Highway Link Configuration

After the parameters and TOD references have been entered, the user may navigate to the base highway link configuration sheet by pressing the "**Base Highway Link Configuration**" navigation button to reach the screen shown in Figure 2.8 and begin developing the base network.

Figure 2.8: Highway Link Configuration

Alternatively, the user may wish to construct the network in the Toolkit Upload File, as noted earlier, in Section 2.3. This Guide *highly* recommends that the analyst first develop a **graphical node-link network** before beginning to code the network into PET. Users may create a network diagram on their own; one example is shown in Figure 2.9 for Waco, Texas.
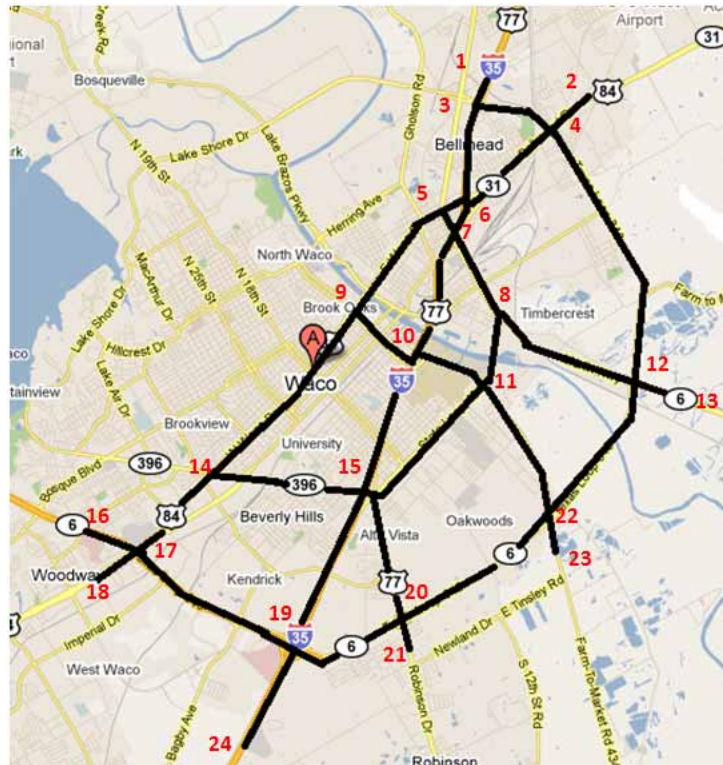
Figure 2.9: User-created Network Diagram—Waco, TX

Alternatively, users may use PET's **Visualization module** in conjunction with Google Earth, as illustrated in Figure 2.10, to create a more automated network diagram, with latitude and longitudes tied directly to link configuration sheets. (See Section 7.0 for more instructions on this automated approach.)
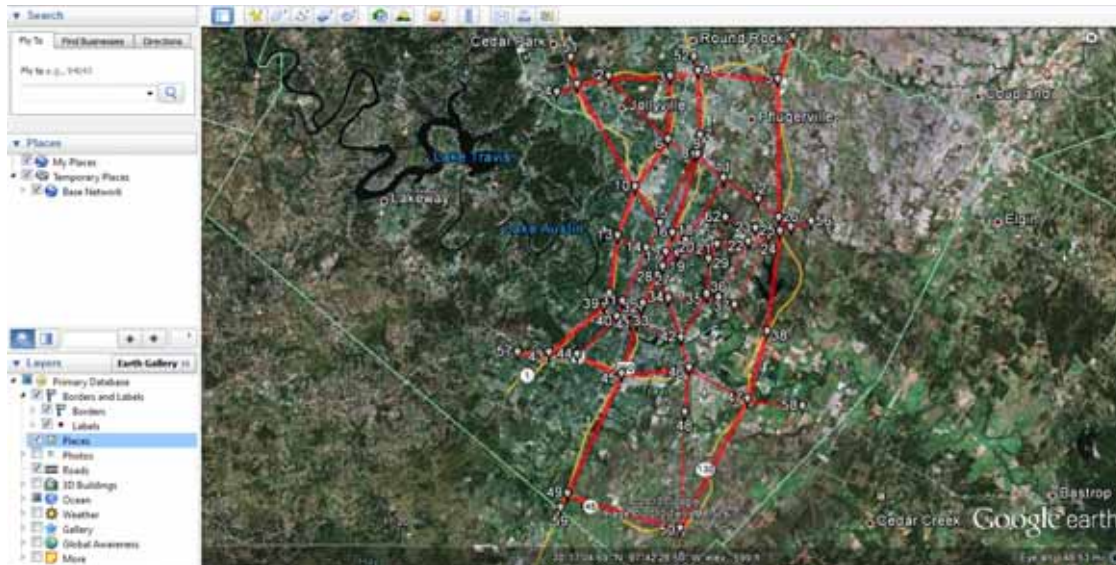
Figure 2.10: Austin Network Produced Using PET's Visualization Component

All links that are coded in the network are directional and **must have a traffic volume (AADT) and capacity of at least 1 vehicle per hour** (vph) for PET to function properly. The **network node numbering system must begin with a node 1 and continue until the last node is reached**. Intermediate nodes cannot be skipped, and the last node number must be the same as the total number of nodes. (This can create issues if users remove nodes later.) Also, **parallel links (joining the same pair of nodes) cannot exist in the network**, since such setups create issues for traffic assignment algorithms. If one or more links do share the same end nodes (for example, frontage roads paralleling a freeway), analysts should simply add another link to the sequence (much like a short on- or off-ramp, for one of the parallel links) to eliminate this anomaly in the network typology. Traffic assignment will work fine with the added node, creating a parallel route without duplication of single-link end points.

In addition to **traffic volumes**, **origin node,** and **destination node**, the user must also enter each link's **capacity** (in vehicles per hour), **facility** type (freeway, arterial, collector, or ramp), the **area type** (urban, suburban, or rural), and **number of lanes**. A **TOD reference** (as described above, in Section 2.5) must also be assigned to each (directed) link to capture swings in traffic that split the 24-hour AADT input for the link. If the link is an arterial, the user must also enter information on local **land use** (rural/residential, industrial, commercial, or office) and the presence of a **median** (none, two-way left turn lane, or divided). These two factors impact expected crash rates, and both attributes may be estimated by using aerial images through tools like Google Earth.

Other link attributes may be entered to improve the analysis accuracy. **Link-specific free-flow speeds**, crash modification factors (**CMFs**), and number of entering and exiting **ramps** for freeways may be input by the analyst. If they are omitted, however, PET will use a default value based on the parameter settings noted in Section 2.4. For more information on CMFs, see Section 8.3.

Finally, some links may have **variable capacity by time of day**. For example, reversible lanes may be open in one direction during the AM peak and midday periods, another direction during the PM peak and evening periods, and closed during the off-peak period. Alternatively, signal timing changes could effectively change link capacity from one time of day to the next. If this is the case, the analyst must enter "1" in the Variable Capacity input for impacted links and enter capacity value for each time of day in the *Managed Lanes with Variable Capacity* input cells.

For a full listing of user inputs and other PET values on the *Highway Link Configuration* sheets, see Appendix B.1.

2.7 Optional Inputs

Users can run PET with only basic link information, but may choose to consider other input features such as tolls, fixed costs, and/or transit. These parameters can be set to unique values for base and alternative scenarios and can often vary further by time of day and vehicle class, for instance.

2.7.1 Tolls

Vehicle tolls may be set by clicking on the "**Base Case Tolls**" navigation button, bringing up the screen shown in Figure 2.11 where the user will be able to set existing tolls by vehicle class and by time of day. Tolls for links, modes, or times of day that are not tolled may be left blank.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1				Project Evaluation Toolkit - Base Case Toll Settings									
2													
3			Go To Navigation Panel										
4													
5													
6													
7													
8													
9													
10								AM Toll Settings					Mid Day Toll Set
11	Link #	From Node #	To Node #	Link Name	Length	Vehicle Class 1	Vehicle Class 2	Vehicle Class 3	Vehicle Class 4	Vehicle Class 5	Vehicle Class 1	Vehicle Class 2	Vehicle Class 3
12	1	51	1	183: N of TT45 - TT45	1	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00
13	2	1	51	183: TT45 - N of TT45	1	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00
14	3	1	10	183: TT45 Loop 1	7.8								
15	4	10	1	183: Loop 1 - TT 45	7.8								
16	5	10	15	183: Loop 1 - Lamar	2.9								

Figure 2.11: Toll Settings

2.7.2 Arterial and Rural Highway Intersections

Arterial and rural highway intersections may be set up by clicking on the "**Base Case Arterial & Rural Hwy Intersects**" navigation button to reach the screen shown in Figure 2.12 where the analyst will be able to enter intersection information.

	A	B	C	D	E	F	G	H	I	J	K
1		Project Evaluation Toolkit - Base Configuration Arterial and Rural Highway Intersections									
2											
3		Go To Navigation Panel		Area Type: 1=Urban, 2=Suburban, 3=Rural							
4				Control: 1=Signalized, 2=Unsignalized							
5											
6						Links and Volumes - Fill in EITHER the *connecting link reference #* OR the *link AADT*					
7	Node #	Node / Intersection Name	Area Type	Control	CMF	Link 1 (Major)	Use Link 1 AADT	Link 2 (Major)	Use Link 2 AADT	Link 3 (Minor)	Use Link 3 AADT
8	1	290 & FM 734	1	SIG		153		154		113	
9	2	290 WB & FM 3177	1	SIG		152					2220
10	3	290 EB & FM 3177	1	SIG		151					1110
11	4	290 & Harris Branch	1	SIG		149		150			200
12	5	290 & Crofford	1	UNSIG		149		150			500
13	6	290 & Giles / JM	1	SIG		147		150		123	
14	7	290 & Chimney Hill	1	UNSIG		147		148			500
15	8	290 & Springdale	1	SIG		145		148		131	
16	9	290 & Tuscany Way	1	SIG		145		146		545	
17	10	290 & Cross Park Dr	1	UNSIG		145		146			500

Figure 2.12: Arterial and Rural Highway Intersections

Note that Figure 2.12's tabled intersection information is used for **crash estimation analysis only**, and PET does not model changes in traffic patterns or speeds based on this information. Therefore, while including all network intersections is preferable, most important is including intersections where traffic volumes are expected to experience significant changes between scenarios.

In order to anticipate crash counts as intersections, the analyst must enter the **area type** (urban, suburban, or rural), **control type** (signalized or unsignalized), and the associated or **entering links'** numbers (from the *Highway Link Configuration* sheets). In many instances, the user's coded network may be focused on or limited to major highway links. PET allows smaller streets to intersect explicitly modeled arterial and rural highway links, yet not be included in the link configuration sheets. In this way, these "unmodeled" (uncoded) links can impact crash count predictions. For example, an intersecting street with 500 AADT probably will not be modeled for its flows, emissions, and traveler route choices, but its presence in the actual network can have an impact on the intersected link's safety performance in PET. Thus, analysts can enter **traffic volumes** in the *Use Link X AADT* fields in lieu of a link number in order to estimate intersection crash rates for intersecting streets that are not coded into the abstracted network.

The following example shows **how to set up the intersection file**. Figure 2.13 illustrates a theoretical network with three intersections. Links L1 through L8 are modeled in the PET-coded network, but the segments running north-south, located west of links L3 through L8, are not modeled. As a result, PET will automatically determine traffic volumes for all modeled links, but the user must separately enter the assumed/known traffic volumes of unmodeled links in the *Use Link X AADT* columns.
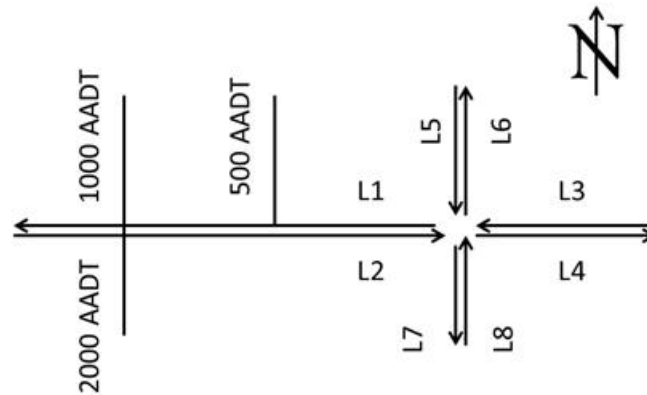
Figure 2.13: Illustration of Modeling an Arterial Intersection

The intersection sheet entries in Table 2.1 generate the appropriate traffic volumes for Figure 2.13's intersection. The first row represents the intersection with links L1 through L8. The major street links entering the intersection are L2 and L3, and the minor street links entering the intersection are L5 and L8. The next two rows represent the two intersections west of the L1–L8 intersection. In these cases, the major street's approaching volume is represented by L1 for westbound vehicles and L2 for eastbound vehicles. Because the minor streets are not modeled/coded in the link configuration tabs, traffic volumes must be directly input into the "Use Link 3/4 AADT" columns. Thus, a value of 500 AADT is used in the second row, while values of 2000 and 1000 AADT are used in the third row, representing the entering traffic volume on each approach. PET relies on these details for estimation of the number (and type) of intersection-related crashes. **Remember that all traffic volumes must be entering vehicle traffic** (i.e., approach volumes on L2, L8, L3, and L5, as shown in the first row of Table 2.1), **and all modeled links should be the links approaching the intersection** (not those leaving the intersection).

Table 2.1: Data Entry Example for the Arterial Intersection in Figure 2.11

Link 1 (Major)	Use Link 1 AADT	Link 2 (Major)	Use Link 2 AADT	Link 3 (Minor)	Use Link 3 AADT	Link 4 (Minor)	Use Link 4 AADT
2		3		5		8	
1		2			500		
1		2			2000		1000

For a full listing of user inputs and other PET values on the *Arterial and Rural Highway Intersection* sheets, see Appendix B.2.

2.7.3 Operational Strategies

PET allows three types of operational strategies that are not modeled as impacting traffic patterns on a day-to-day basis, but rather as changing the way that traffic events (such as crashes, weather events, and sporting events) are handled. These operational strategies are **Advanced Traveler Information Systems** (ATIS), **Incident Management** (IM), and **Speed Harmonization** (SH).

ATIS projects may be variable message signs, highway advisory radio, mobile phone applications, and the like. IM strategies represent roving freeway service patrols, incident detection cameras with monitoring from a traffic operation center, and other methods for early incident detection and response. SH strategies typically use overhead gantries with variable speed limits that attempt to better synchronize roadway traffic speeds under congested conditions. Analysts do not need to enter any information on these sheets unless at least one of their scenarios will be implementing one or more of these strategies. For more information on using these operational strategies, see Section 3.6.

2.7.4 Origin-Destination Fixed Costs

Users may specify a node-specific fixed cost by **time of day** and/or **vehicle class** for each network node. These **optional** costs may represent parking costs, time delays due to walking, or any other cost associated with a specific node. The values are empty by default but the user may manipulate them through the *Fixed Costs* sheets, available for the base case and all three scenarios in both **initial and design years** (Figure 2.14). While these costs may influence travel behavior when running the travel demand model, they are considered **private payment transfers** and are not included in strict financial analyses, as toll revenues are, for instance. If a user wants to consider effects of increased parking costs on city-owned parking areas, this direct revenue will not be captured as a profit automatically in PET, since origin-destination costs are general and can represent more costs than pure monetary fees (i.e., fixed costs may represent travel-time cost of walking, which doesn't involve real exchange of dollars). However, users should note that these costs do impact monetary benefit calculations, which include social considerations of traveler welfare and reliability. (For instance, imposing fixed costs between nodes may increase travel costs and therefore reduce traveler welfare benefits, but may reduce congestion and raise link reliability.)

Figure 2.14: Fixed Costs Settings

2.7.5 Transit

PET 2.0 introduced **optional** transit features into the network modeling, allowing users to create "arcs" of transit service across several nodes. Each arc represents a service line that can connect up to 10 nodes in a network (as a series of stops along the bus route, for example). For a given arc, users must specify all **nodes** and total **arc headway** (time it takes to travel across all arc nodes). If the route operates in both directions (e.g., northbound/southbound or eastbound/westbound), each direction must be specified as a separate route in PET. Additionally, users may specify unique headways by **time of day**, to reflect variations in route service levels

across peak and off-peak periods (Figure 2.15). The specific form of public transit is not specified and may capture any rail or bus system.

Figure 2.15: Transit Settings

2.7.6 Electric Vehicles and Average Fuel Economy

PET allows users to specify unique attributes of plug-in electric vehicles (EVs) among their fleets. Plug-in EVs are vehicles that run largely or purely off battery power for at least some portion of the time, and can be powered by the electricity grid, rather than always having to fill up as gas stations. This category does not include standard hybrid electric vehicles (HEV), such as the Toyota Prius HEV and Ford Escape HEV. HEV fuel economies and emissions production are already reflected in MOVES emissions rates for US fleet expectations. While CO_2 levels can and do vary noticeably between HEVs and internal combustion engines (ICEs) for the same vehicle model, their other emissions are generally not so different, due to vehicle-by-vehicle emissions laws. Plug-in EVs promise the greatest impact on MOVES rates, and require a look at the process of generating electricity, for emissions from power plants.

Users can specify plug-in EV parameters by navigating to the *Vehicle Fleet Information* sheet. Here, users may specify the number of light-duty-vehicle (LDV) VMT for two plug-in vehicle types: (1) **battery-electric vehicles**, or vehicles relying only on batteries for their propulsion, like a Nissan Leaf or Ford Focus Electric, and (2) **plug-in hybrid electric vehicles** (PHEVs), which include ICEs (for when the charge runs low), like the Chevrolet Volt. Since PHEV emissions impacts depend on how frequently the ICE is used, users can specify the average share of electric-powered/electrified PHEV miles. Figure 2.16 shows inputs for EV assumptions in both the initial and design years. Defaults represent US 2010 EV registrations and sales, since no data or projections exist for EVs' VMT (EIA 2010). Future market projections and efficiencies should reflect project lifetimes, since EV shares are expected to rise over time. Khan and Kockelman (2012) and EIA (2010) may be helpful sources, giving analysts a sense of electrified miles shares for EV-owning households and long-term EV sales shares. PET users can also change how efficient the average EV battery will be in their alternatives, in terms of miles per kWh; this assumption impacts how much electricity (and therefore energy) is required to operate the vehicle per mile. The current default of 3.5 mi/kWh reflects small-car EVs with air conditioning, heating, or other loads on the battery and propulsion system. Inputs from Figure 2.16 determine the electrified percentage of VMT and report an "EV Emissions Modification Factor," which is multiplied with all typical emissions, removing all electrified miles from emissions calculations. Using defaults from 2010, the EV modification factor is miniscule.

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Electric Vehicles Parameters

Electric Vehicle VMT Share and Efficiency (PHEVs and BEVs)

	Initial Yr	Design Yr
PHEV % of LDV VMT	0.05%	0.05%
PHEV % miles Electric	64%	64%
BEV % of LDV VMT	0.05%	0.05%
Average EV Efficiency (miles/kWh)	3.5	3.5
EV Emissions Modification Factor	0.999	0.999

Note that % VMT estimates are for lighty-duty vehicles (LDVs)

Figure 2.16: Fleet Makeup and Parameters of EVs

Since EV battery power comes from upstream electricity-generating facilities (like power plants and wind farms), users can specify a unique emissions profile based on a mix of power sources, to help reflect the total emissions changes from scenarios that offer more EVs and more electrified miles. Per-mile emissions for five pollutants (CO_2, CH_4, N_2O, NO_x, and SO_2) replace a standard LDV's MOVES-based emissions for initial and design years; PET will interpolate emissions linearly or exponential (based on user specification in the *Summary Input Information* sheet) between these given values. Though electricity generation may produce other emissions, these five are the most prevalent. These species are also the only 5 reported (among the 14 species reported by PET) by the EPA's e-GRID database, which contains emissions information on all U.S. power plants by region. PET's default values are for the Energy Reliability Council of Texas (ERCOT) region in 2007, which covers nearly all of Texas, with an average year-long mix of 64% natural gas, 20% coal, 5% nuclear, and 10% renewable energy feedstocks. Figure 2.17 shows parameters for average power plant emissions in terms of grams per kilowatt-hour in the Electric Vehicles Parameters field in the *Vehicle Fleet Information* sheet. Users may update this information with state-specific data from the EIA (2010) and/or with more specific data from the EPA's e-GRID (2010).

Pollutant Species	Average Powerplant Emissions (g/kWh)		EV Electrified Emissions(g/mi)	
	Initial Yr	Design Yr	Initial Yr	Design Yr
CO2	586.16	586.16	167.47	167.47
CH4	0.00806	0.00806	0.0023	0.0023
N2O	0.00635	0.00635	0.0018	0.0018
Nox	0.3348	0.3348	0.0957	0.0957
SO2	1.1592	1.1592	0.3312	0.3312

Figure 2.17: Power Plant Emissions Profiles

Finally, the analyst may want to adjust the fleet's **average fuel economy** estimate. To do so, click the "Fuel Economy" navigation button. For each analysis year, an average fuel economy is provided, which is a weighted combination of 28 types of light and heavy vehicles and the fuel that they are estimated to consume in a single mile of travel. The analyst may replace PET default values with updated estimates by entering a new value in the "Alt. mpg" column as shown in Figure 2.18. User-defined alternatives will override defaults in the "mpg" column.

year	Alt. mpg	mpg	factor
1994	15	15	0.559701
1995	15.21	15.21	0.567537
1996	15.34	15.34	0.572388
1997		17.22107	0.642577
1998		17.18391	0.641191
1999		17.11453	0.638602
2000		17.07526	0.637137
2001		17.03674	0.635699
2002		16.97789	0.633503
2003		16.91155	0.631028

Figure 2.18: Estimated Annual Vehicle Fleet Fuel Efficiency
(Note: the mpg column is based on a LOOKUP function from a larger table. Its values are updated automatically with any users entries in the Alt. mpg column.)

Average fleet fuel economy estimates between 2010 and 2050 were obtained from Kite (2009) using MOBILE 6.2 default values and estimates from West (1997). (MOBILES 6.2 was the official EPA emissions modeling software used prior to MOVES2010a.) West's data set assumes a single vehicle with an average fuel efficiency of 26.8 mpg. Therefore, a fleet fuel economy factor (total estimated fuel consumption divided by VMT) is applied to account for the diverse range of individual vehicle fuel economies.

Chapter 3. Developing Alternative Scenarios

Once the global parameters, time of day (TOD) settings, the base network, and intersections have been developed and verified, the user may begin creating alternative scenarios. This relatively quick process may be accomplished largely by copying the base case scenario, conducting targeted modifications, and developing a cost and traffic growth estimate. Section 3 describes processes that allow the user to develop up to three alternative scenarios. If more than three alternative scenarios are desired, the user may copy the Excel file, save it with another name and develop additional scenarios.

3.1 Highway Link Configurations

All scenarios require that the user specify a network particular to that scenario, even if it is the exact same as the base case scenario. And the **network typology** (i.e., the numbering of nodes and links) **must be the same across all scenarios** to avoid algorithm confusion. Some links may have near-zero capacity, demonstrating that they do not exist in the alternative under study (e.g., under a base case/no-build setting). To generate an alternative scenario, the easiest way is to click the "Alternative Scenario *X* Highway Link Configuration" navigation button, then press the "**Copy Base Network**" button as shown in Figure 3.1:

Figure 3.1: Copying the Base Network

This will copy all of the network information from the *Base Highway Link Configuration* sheet to the *Alternative X Highway Link Configuration* sheet. Note that the AADT and TOD reference station numbers are not copied to the alternative scenario highway link configuration sheet. This is because the alternative scenario has not yet been realized and therefore, unlike the base case scenario, the actual traffic volumes are not available.

Once the highway link configuration is copied from the base case scenario, the analyst may **adjust link characteristics** to fit the new scenario. The link classification may be updated,

capacity expanded, free-flow speed changed, managed lanes implemented, or a variety of other scenarios may be pursued.

The analyst may also wish to **add** one or more **links or nodes** in the alternative scenario that do not exist in the base case scenario. **To do so, the analyst *must* go back to the base case scenario and add those links and nodes**. This step is critical as the base case and the alternative case scenarios must all have the same number of links and nodes. However, since the link should not be available to traffic in the base case scenario, the user should enter a base case scenario capacity and AADT of 1 for the new traffic link. This step will allow the travel demand model to operate properly while preventing the new link from having any substantial influence on the predicted base case scenario outcomes.

3.2 Arterial and Rural Highway Intersections

Similar to the highway link configuration sheets, arterial and rural highway intersections for the alternative scenarios may be loaded by clicking "Alternative Scenario *X* Arterial & Rural Highway Intersects" then pressing the "**Copy Base Intersections**" button. This will copy all arterial and rural highway intersections from the base case scenario to the alternative scenario. The user may then **modify intersections** in the alternative scenario as required. The intersection traffic control device and the crash modification factor are the two items most likely to change. The area type, the traffic link, or the incoming traffic volume on non-modeled links are less likely to change between the base case and the alternative case scenario.

Note: the alternative scenario and the base case scenario should usually model the exact same intersections. Otherwise, one scenario will estimate crashes at an intersection while the other scenario will assume that no crashes are occurring there, even though the intersection should exist. The only instances where new intersections should be added or old ones deleted is when a new intersection is being created (for example, by extending a dead-end street to intersect another roadway) or removed (for example, by converting an arterial to a freeway resulting in grade separation—though this may also result in new intersections between the previously intersecting road and the new off ramps).

3.3 Tolling, Fixed Costs, and Transit

Tolls, fixed costs (at trip origins and destinations), and transit lines in the alternative scenarios may also be set by the user. The easiest way to is to press the "Alternative Scenario *X* Tolls," "Alternative Scenario *X* Fixed Costs," or "Alternative Scenario *X* Transit" navigation button, and then press the "**Copy Base Settings**" button. Then, if the user wishes to **modify** any of the **tolling rates**, **fixed costs,** or **transit parameters,** he or she may accomplish this by changing the appropriate cell data for any links, transit arcs, vehicle classes, and times of day, as desired.

3.4 Engineer's Estimate

Once the base case scenario and alternative scenarios have been developed, the user must develop cost estimates for each of the alternative scenarios. To get to the *Engineer's Estimate* sheet, click on the "**Engineer's Estimate**" navigation button, which will bring up the screen shown in Figure 3.2:

	Lane Miles	Const Cost per Lane Mile	ITS / Signal / Electrical	Bridges & Structures	Utility & Other Fixed Costs	Construction Subtotal	Traffic Control	Environmental Construction
						Project Evaluation Toolkit - Engineer's Estimate		
No Build						$0	0.0%	0.0%
Freeway Upgrade	20.8	$5,732,000				$119,225,600	0.0%	0.0%
Tollway Upgrade	20.8	$5,732,000	$6,316,000			$125,541,600	0.0%	0.0%
Tolling by TOD	20.8	$5,732,000	$6,316,000			$125,541,600	0.0%	0.0%
ATIS						$0	0.0%	0.0%
Incident Management						$0	0.0%	0.0%
Speed Harmonization						$0	0.0%	0.0%

	Design as % of Const Costs	Design	ROW Purchase	Construction Engineering	Construction Engineering	Contingencies	Contingencies	Overhead & Indirect Costs
No Build	0%	$0	$0	0.0%	$0	0.0%	$0	0.0%
Freeway Upgrade	10%	$11,922,560	$0	0.0%	$0	0.0%	$0	0.0%
Tollway Upgrade	10%	$12,554,160	$0	0.0%	$0	0.0%	$0	0.0%
Tolling by TOD	10%	$12,554,160	$0	0.0%	$0	0.0%	$0	0.0%
ATIS	0%	$0	$0	0.0%	$0	0.0%	$0	0.0%
Incident Management	0%	$0	$0	0.0%	$0	0.0%	$0	0.0%
Speed Harmonization	0%	$0	$0	0.0%	$0	0.0%	$0	0.0%

	Design	ROW Purchase	Construction Engineering	Construction Cost	Contingencies	Overhead & Indirect Costs	Total Initial Project Costs
No Build	$0	$0	$0	$0	$0	$0	$0
Freeway Upgrade	$11,922,560	$0	$0	$119,225,600	$0	$0	$131,148,160
Tollway Upgrade	$12,554,160	$0	$0	$125,541,600	$0	$0	$138,095,760
Tolling by TOD	$12,554,160	$0	$0	$125,541,600	$0	$0	$138,095,760
ATIS	$0	$0	$0	$0	$0	$0	$0
Incident Management	$0	$0	$0	$0	$0	$0	$0
Speed Harmonization	$0	$0	$0	$0	$0	$0	$0

Figure 3.2: Engineer's Estimate (not all cost components shown)

The key values used are from the engineer's estimate at later stages when developing summary measures (net present value, benefit-cost ratio, etc.), shown in bold outlines at the bottom right. These values include the **Total Initial Project Costs**, the **Added Annual Maintenance**, the **Salvage Value**, the **Maintenance and Rehabilitation Project Year** and the **Maintenance and Rehabilitation Project Cost**.

The **Total Initial Project Costs** are developed from a number of other items, including design, right-of-way, construction engineering, construction costs, contingencies, and overhead and indirect costs. Construction costs are broken down into several categories. The Toolkit user must enter values for lane-miles to be constructed, cost per lane-mile, signal or electrical and ITS costs, bridge and structure costs, utility costs, and other fixed costs. Traffic control and environmental construction (for implementation of the erosion and sediment control plan [ESCP], storm water pollution prevention plan [SWPPP], and other required environmental mitigation) are also required construction cost inputs, though the analyst must enter these as a percentage of base construction costs. Construction costs are then totaled for all component categories.

The analyst must next enter right-of-way costs, as anticipated for each project scenario. Design, construction engineering, contingencies, and indirect costs are all required input entries, represented as percentages of total project construction costs.

Salvage Value is the expected value at the end of the project life for the scenario alternative, relative to the no-build scenario. (For example, a brand-new facility may have far more salvage

value than a shoulder widening or lane addition on an existing roadway.) The analyst may enter a salvage value for each scenario alternative, as well as anticipated annual changes in maintenance costs as compared to the no-build/based-case scenario.

Finally, some scenario alternatives may require significant interim expenditures (e.g., *major rehabilitation and maintenance projects* for base-case scenarios) before the project's design life elapses. In these cases, the analyst should input the anticipated interim project construction year and comprehensive interim project cost. For example, a lane-add project could have a 20-year design life but require existing lanes to be repaved within 10 years of the expected project completion date. One scenario may add new lanes while not modifying any existing lanes, while a second scenario may reconstruct the entire roadway. In the first scenario (and in the no-build scenario), the analyst should input the year and value of the anticipated interim project construction (for repaving the existing lanes).

3.5 Traffic Growth

The final input component before running the scenario is the *Travel Growth* sheet. This sheet may be accessed by pressing the "**Travel Growth Rates**" navigation button, which should bring up the screen shown in Figure 3.3:

	A	B	C	D	E	F	G	H	I	J
1					Project Evaluation Toolkit - Travel Growth Rates					
2										
3		*Go To Navigation Panel*						Base Annual Growth Rate	1.0%	
4								Growth Rate is	Exponen	
5								Project Life (Years)	20	
6								Base Traffic Growth over Project Life	22.72%	
7										
8										
9				Initial Year				Design Year		
10			Production Growth		Attraction Growth		Production Growth		Attraction Growth	
11		Node	Base Initial Growth	Initial Growth	Base Initial Growth	Initial Growth	Alternate Growth Rate	Life Growth	Alternate Growth Rate	Life Growth
12		1	5.0%	5.0%	5.0%	5.0%		22.7%		22.7%
13		2		0.0%		0.0%	2.0%	48.6%	2.0%	48.6%
14		3		0.0%		0.0%	2.0%	48.6%	2.0%	48.6%
15		4		0.0%		0.0%		22.7%		22.7%
16		5		0.0%		0.0%		22.7%		22.7%
17		6		0.0%		0.0%		22.7%		22.7%

Figure 3.3: Travel Growth Rates

This sheet allows the analyst to **model** certain areas as experiencing **different travel demand growth** than other areas. The model will assume that all growth is zero percent for the first year and the base growth rate compounded over the design life for the design year. The user may adjust travel demand for individual nodes by changing the base initial growth or design year alternative growth rate. The user may also wish to increase the base rate for all nodes if the project will be constructed well into future. **Caution:** if this rate is increased, the expected design year growth rate will not change automatically and must also be adjusted, either by changing the base growth rate (in the *Summary Input Information* sheet) or the alternative growth rate for all nodes.

Before adjusting the travel growth rates, users must understand how PET uses this information. PET's travel demand model operates by first estimating a trip table for each TOD period, based on existing traffic link counts. Then the trip table is created for the initial and design year (though the initial year trip growth file will be all zeros unless alternate base initial growth values are given). The travel growth between each origin-destination pair is equal to the average of the origin's production growth and the destination's production growth. Thus, for the values shown in Figure 3.3, the number of trips from origin 1 to destination 2 would be increased from the base trip table by 2.5% in the initial year [(0+5)/2=2.5] and 35.65% in the design year [(22.7+48.6)/2=35.65].

3.6 The Operational Strategies

PET's Main Toolkit File (sketch_toolkit.xlsm) in conjunction with the travel demand model evaluates impacts to users and the transportation system on a network level. These components can accommodate strategies, including capacity expansion, reversible lanes, variable tolling by time of day, and/or mode and shoulder lane use. Other operational strategies such as Advanced Traveler Information Systems (ATIS), speed harmonization, and incident management do not have the same impacts on overall network operation. These strategies require users to run the travel demand model for the Base Case (no-build) scenario only. ATIS and incident management strategies are designed to enhance system response to incidents that occur at random intervals on the transportation network. Speed harmonization also does not directly impact the normal transportation network operations. Speed harmonization tends to cause all vehicles to travel at the same pace, rather than causing substantial changes in overall travel times or available roadway capacity.

To develop an operational strategy, first **ensure that the transportation network has been already coded**. Users can navigate to the *ATIS, Incidence Management,* and *Speed Harmonization* sheets to enter data for each operational strategy, as desired, and check parameters in the *Summary Input Information* sheet under the Operational Parameters panel as shown in Figure 3.4:

Operational Parameters				% Total Crashes in
			Hour Beginning	Hour
Max Proj Life = 50 yrs	Project Life		Midnight	1.53%
Operational Strategy	10		1:00 AM	1.53%
Incident Growth Rate	1.0%		2:00 AM	1.53%
			3:00 AM	1.08%
			4:00 AM	1.08%
Avg. Vehicle Occupancy	1.60		5:00 AM	1.08%
Avg. Val Trav Time($/hr)	$10.75		6:00 AM	4.17%
			7:00 AM	4.17%
			8:00 AM	4.17%
Crashes AM Peak	25.9%		9:00 AM	4.48%
Crashes Mid Day	27.4%		10:00 AM	4.48%
Crashes PM Peak	21.0%		11:00 AM	4.48%
Crashes Evening	12.3%		Noon	6.42%
Crashes Off Peak	13.4%		1:00 PM	6.42%
			2:00 PM	6.42%
			3:00 PM	8.13%
Lane Blocking Incidents per Crash		2.07	4:00 PM	8.13%
Current Average Duation of Lane Blocking			5:00 PM	8.13%
Incident (min)		65	6:00 PM	4.77%
			7:00 PM	4.77%
			8:00 PM	4.77%
			9:00 PM	2.77%
			10:00 PM	2.77%
			11:00 PM	2.77%

Figure 3.4: Operational Parameters

After reviewing the parameters, the user must develop an **engineer's estimate**, as done for other project analyses.

The user should next go to the relevant sheet corresponding to the operational strategy that is to be pursued. Here the user should **enter key assumptions** regarding the specific scenario. Inputs for incident management are shown in blue and green in Figure 3.5:

Project Evaluation Toolkit - Incident Management

	Incident Management					1,3-Butadiene
Project Duration (years)	10					
Annual Traffic Growth (%)	1%		Reductions	Initial Year		0.00
Annual Incident Growth (%)	1%			Design Year		0.00
Number of Links Impacted	6		Base Level	Initial Year		7.89
	Initial Year	Design Year		Design Year		2.71
	2015	2025		With Inc Mgt	Initial Year	7.89
Incidents per Year on Impacted Links	14330	7669			Design Year	2.71
Total # Vehicles on Impacted Links (AADT)	1,973,747	2,186,466				
						% Of Crashes
Lane Blocking Incidents per Crash	2.07	2.07		IM Activation Times (0/1)		In Period
Average Incident Duration (hours)	1.08	1.08		AM Peak	1	25.9%
Average Incident Duration with Incident Management (hours)	0.833	0.833		Mid Day	1	27.4%
Annual Travel Time Savings (hours)	868,929,034	1,066,318,046		PM Peak	1	21.0%
Annual Travel Time Monetary Benefits ($)	$14,945,579,386	$18,340,670,390		Evening	0	0.0%
Warnings	Present	Present		Off Peak	0	0.0%

Figure 3.5: Incident Management Summary

The final operational strategy setup step is to enter the **link numbers** and **alternative link-specific settings** for impacted links. The impacted link numbers will correspond to the link numbers in the Main Toolkit File. The user may also adjust link-specific alternative input settings. These settings will change the default link value and are shaded blue. The effects of using link-specific alternative inputs are shown in Figure 3.6.

				Initial Year			
#Incidents on Link	Alt Avg Incident Duration	Avg Incident Duration	Alt Avg Incident Duration w IM	Avg Incident Duration w IM	% Incidents Peak Hour	Alt Arrival Rate (% of AADT)	Arrival Rate (% of AADT)
15	2	2	1.5	1.5	0.6090722		6.50%
15	2	2	1.5	1.5	0.6090722		6.50%
29		1.083333333		0.833	0.6090722		6.50%
29		1.083333333		0.833	0.6090722		6.50%
43		1.083333333		0.833	0.6090722		6.50%

Figure 3.6: Link-Specific Alternative Inputs for Incident Management

In this example, the first two links model incident durations of 2 hours and incident durations with incident management of 1.5 hours by using a link-specific alternative value. The remaining links use the default current incident duration of 1.083 hours and incident durations with incident management of 0.833 hours.

For additional guidance, the user may refer to Section 10.6. For a full listing of PET operational strategy parameter value defaults, sources, and descriptions, see Appendix B.4.

Chapter 4. Running the Travel Demand Model

PET's travel demand model is intended for **sketch purposes only** and is **not a substitute for official modeling software**. Since PET's abstracted networks are limited to 300 links, PET cannot duplicate the detail and precision of typical travel demand models and should be applied only during preliminary evaluations and project comparisons. Alternatively, PET's back-end calculations (for traveler welfare, reliability valuation, emissions, crash counts, benefit-cost ratios, and so forth) can be used on a region's full-scale travel demand model outputs. Thus, PET is useful for preliminary and final project evaluations, depending on whether PET's sketch-level demand model is used.

Before attempting to run the travel demand model, the analyst should have reviewed and modified parameters, developed networks, set tolling rates, input intersections, estimated scenario costs, and reviewed the expected travel growth throughout the transportation network. If all of these components have been developed and reviewed, the analyst may click the "**Project Evaluation Toolkit Home**" navigation button to begin the process of running the travel demand model (Figure 4.1).

Figure 4.1: PET Home

Typically the user should set the Travel Demand Estimation **analysis year** to "All" and the scenario to "All." These settings will result in the travel demand model running all scenarios in the initial and the design year. Alternatively, the user may want to just run the travel demand model for the initial or the design year, which may be accomplished by entering "IY" or "DY" in the analysis year. Or the user may wish to run only one scenario, in which case "Base" should be

entered for the **analysis scenario** if running the base case scenario or "1," "2," or "3" should be entered if running one of the alternative scenarios.

In the **Perform All Tasks without Stopping** input cell the user should enter "Y" if he or she wishes for the travel demand model to begin on the selected task then continue until all results are loaded, or "N" if the user wishes for the travel demand model to proceed one task at a time, then exiting so that the user may examine the files generated by the Main Toolkit File and travel demand model components.

Once the travel demand model begins running, the **Status bar** will display the current status of the travel demand modeling process. If the user is conducting sensitivity testing, the **Sensitivity Testing status bar** will also give travel demand model status updates at regular intervals. The Status bar and Sensitivity Testing status bar are shown in Figure 4.2.
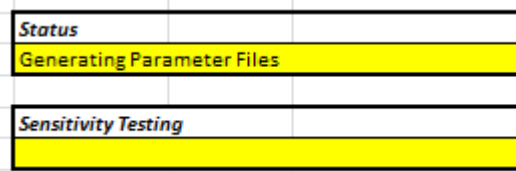
Figure 4.2: Status Bar and Sensitivity Testing Status Bar

Users should be aware that the travel demand modeling procedure may take a while to run. It takes approximately 1 hour to run 4 scenarios (3 alternative scenarios + base case) for the initial and design years for a 194-link, 62-node network, using a desktop computer with a 2.4GHz processor and 4.0 GB of RAM. This time includes all initial file generation and results uploading processes, as well as running the actual travel demand model. If sensitivity testing is conducted, the process will take even longer, with greater amounts of time required as more inputs are varied.

4.1 Parameter and Error Review

The first thing that the user should do when getting ready to run the travel demand model is to **verify the input summary checklist** (some summary checklist reports are shown on the right in Figure 4.1). The checklist includes user input values, a number of factors that may be verified (number of scenarios, initial year, design life, etc.), as well as other components that simply return an "OK" or "Error" message. If any of the error checks reports an error, the analyst should read the corresponding error check message and address the issue. For example, if an error is reported for "Alternative Scenario 1 - Road Class Entered on All Links," the analyst should go to the *Alternative Scenario 1 Highway Link Configuration* sheet and enter the appropriate road classification values for all links with missing values.

4.2 Preparing Input Data and Parameter Sets

Once the parameters have been verified and errors checked, the user may begin the travel demand model process by clicking the "**Prepare Input and Parameter Sets**" button. This will create a number of files including a parameter file for the initial and design year (Parameter_List_IY and Parameter_List_DY), a network file for each scenario-TOD

combination (Input_Network_Base_TOD1, Input_Network_Alt_1_TOD4, etc.), a growth file for the initial and design years (Demand_Growth_IY and Demand_Growth_DY), and a traffic volume file for each time of day (Input_Volumes_TOD1, Input_Volumes_TOD2, etc.).

If the user is conducting **sensitivity testing** (set in the *Summary Input Information* sheet), the travel demand model will create the base files, but will also create additional files to be placed in the STInput file folder. If the user sets parameters in the parameter file to vary, PET will generate one parameter file for each sensitivity testing trial (or more likely two if the initial year and design year are both being analyzed), appending "_*X*" at the end of the file name where *X* is the trial number. Thus for the third sensitivity testing trial, a "Parameter_List_IY_3" and a "Parameter_List_DY_3" file will be placed in the STInput file folder. Similar processes will also generate multiple sensitivity testing files in the STInput file folder for networks and travel growth if values within these file are set to vary. Finally, a single variation file ("VariationFile") is created in the base directory; it contains the parameter variation values for all parameters that are set to vary.

4.3 Estimating the Base Trip Tables

The next step of the travel demand modeling process is the trip table estimator. This process automatically activates if the user has selected "Y" in the Perform All Tasks without Stopping input cell. Alternatively the user can activate this process by clicking "**Estimate Base Trip Matrix**" if all of the input files have been generated. This process runs the *tdm_matrix.exe* application to estimate a trip table based on traffic link counts and the existing network. One trip table is then created for each TOD period (Trip_Matrix_OD_TOD1, Trip_Matrix_OD_TOD2, etc.) and placed in the base file directory.

4.4 Estimating Network Flows

After the trip tables have been generated, the travel demand model estimates new traffic flows for each scenario and each year of the analysis. This process automatically activates if the user has selected "Y" in the Perform All Tasks without Stopping input cell. Alternatively the user can activate this process by clicking "**Estimate Network Flow Pattern**" if the trip table has already been estimated and all of the input files have been generated. This process runs the *tdm_flow.exe* application to estimate total traveler welfare changes versus the base case scenario, as well as predicted link-level user class, vehicle mode, and TOD period traffic flows. This will create one output volume file and one output summary file for each scenario and year:

- Output_Volumes_Base_IY, Output_Volumes_Alt_2_DY, etc., and

- Output_Summary_Base_DY, Output_Summary_Alt_3_IY, etc.

If the user is conducting **sensitivity testing**, additional volume output and summary files will be created in the STOutput file folder, appending "_X" on to the end of each file name, where *X* is the sensitivity testing trial number. In this case, the results will automatically be uploaded, and parameters will be varied in the Main Toolkit File as was previously determined. Next, the key outputs will be recorded in the *Sensitivity Testing* sheet and the next sensitivity testing trial results will be loaded. This process will continue until all sensitivity testing trial results have been uploaded and recorded.

4.5 Reading Computational Results

The final step of the travel demand modeling process is reading back the results generated by the travel demand model. This process automatically activates if the user has selected "Y" in the Perform All Tasks without Stopping input cell. Alternatively the user can activate this process by clicking "**Read Computational Results**" if the network flow patterns have already been estimated. This will upload the output volume and summary files estimated by the travel demand model and store them in PET's volume output sheets.

Chapter 5. Interpreting Toolkit Results

Once the travel demand model has been successfully run, the analyst may review several PET sheets in order to understand the impacts of the various scenarios.

5.1 The Toolkit Output Summary

The most critical results information is shown in the *Output Summary* sheet, which may be accessed by pressing the "**Output Summary**" navigation button. PET's output summary contains several larger components, including *cost information*, *benefits information*, *economic summary measures*, *project financing measures*, and overviews of *crashes changes*, *emissions changes*, and *VMT and splits by time of day and travel mode*.

The **project cost** information is relatively simple to understand and is obtained from the information given to PET in the *Engineer's Estimate* sheet. This section contains summaries of initial year costs as well as changes in annual maintenance and operations costs, salvage value, and interim year (maintenance and rehabilitation) project cost and year for each scenario (see Figure 5.1).

		Scenarios			
		No Build	Freeway Upgrade	Tollway Upgrade	Tolling by TOD
Initial Project Costs	Right of Way	$0	$0	$0	$0
	Design	$0	$11,922,560	$12,554,160	$12,554,160
	Construction	$0	$119,225,600	$125,541,600	$125,541,600
	Other	$0	$0	$0	$0
Total Initial Costs		$0	$131,148,160	$138,095,760	$138,095,760

Figure 5.1: Output Summary Project Cost Information

The next major section is the **monetary benefits** section. Users should note that these measures include **traveler welfare** (consisting of changes in travel time and operating costs), travel time **reliability, tolling,** and **crash** impacts. This is reported for each scenario in the initial year and the design life year. Monetizing/valuing traveler welfare and reliability does not increase project revenues and affect financing, however. Strictly monetized financial results (based on agency costs and toll revenues) are called **project financing** measures, and these are presented in separate tables within the *Output Summary* sheet, discussed in this chapter. Monetized social benefits, including traveler welfare and reliability, and emissions and crash impacts (if users wish to monetize these) are used in conjunction with scenario costs, to assess each scenario's economic summary measures: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit/Cost (B/C) Ratio, and Payback Period (PP). Benefits and economic summary measures are shown in Figure 5.2:

	No Build	290 Freeway Upgrade	290 Tolled Freeway	290 Tolling by Vehicle Class
Initial Year Monetary Benefits	$0	$22,262,068	$2,289,177	$1,959,306
Traveler Welfare	$0	$14,250,951	-$5,706,191	-$6,015,091
Reliability	$0	$7,296,550	$7,298,079	$7,297,628
Crashes	$0	$714,567	$697,290	$676,768
	No Build	290 Freeway Upgrade	290 Tolled Freeway	290 Tolling by Vehicle Class
Design Life Year Monetary Benefits	$0	$75,178,848	$43,636,550	$53,175,156
Traveler Welfare	$0	$29,713,993	$3,279,426	$7,081,037
Reliability	$0	$44,429,506	$39,317,391	$45,002,714
Crashes	$0	$1,035,348	$1,039,732	$1,091,406
Net Present Value	$0	$449,553,640	$116,195,343	$147,567,514
Internal Rate of Return	N/A	53.77%	13.57%	14.90%
Benefit / Cost Ratio	N/A	9.07	2.60	3.03
Payback Period	N/A	3.2	11.7	11.1

Figure 5.2: Output Summary Monetary Benefits and Economic Summary Measures

After examining the overall estimated benefits and costs, the analyst may wish to examine **project financing measures**, the next summary output section, as shown in Figure 5.3:

	No Build		290 Freeway Upgrade	
Annual Tolling Revenues (Thousands $)	Initial Yr	Design Yr	Initial Yr	Design Yr
Total	$122,046	$141,480	$122,046	$141,636
Change vs No Build Scenario	$0	$0	$0	$156

Project Financing (Thousands $)	No Build	290 Freeway Upgrade	290 Tolled Freeway	290 Tolling by Vehicle Class
NPV of New Tolling Revenues	$0	$782	$199,087	$231,440
NPV of Initial and Future Project Costs	$17,540	$73,246	$90,080	$90,080
Project Financing Perspective NPV	-$17,540	-$72,464	$109,007	$141,361
Project Financing Perspective IRR	N/A	N/A	22.2%	26.6%
Project Financing Perspective PP	N/A	>20 years	6.6	5.5
NPV of Project Impacts	$0	$505,259	$188,735	$220,107
Agency Perspective NPV	-$17,540	$432,795	$297,742	$361,467

Figure 5.3: Output Summary Project Financing Evaluation

This section reports the predicted total tolling revenues, changes in tolling revenues, and NPV of tolling revenues for each project scenario. PET **compares scenario cost information against the projected revenues** in order to develop this project financing perspective in terms of NPV, IRR, and PP. Finally, the NPV of the project impacts are added to the estimated NPV of total project impacts to obtain an "Agency Perspective NPV." In this way, transportation agencies can evaluate projects using a financing perspective, while still weighing the predicted benefits or costs to the traveling public of each alternative scenario. Users should be aware that rarely do project revenues ("benefits" from the agency perspective) recover total project costs, since most networks have hundreds of non-tolled routes and compete with revenue-raising links and routes. Fortunately, when all the benefits to travelers through traveler welfare and travel-time reliability estimates are recognized, many projects' (social and other) benefits do cover their costs, as calculated in the **monetary benefits** tables provided in PET's *Output Summary* sheet.

In addition to economic summary measures and monetary costs and benefits, PET's *Output Summary* sheet provides users a method to quickly compare impacts that may not be monetized by the user, such as **crashes** and **emissions**. Changes in crashes (by severity) and emissions (by species) are reported for each scenario's initial year and design year, as shown in Figure 5.4. Plots of their interpolated values, relative to the Base Case scenario's values, are provided in the *Summary Charts* sheet.

		No Build		290 Freeway Upgrade	
Average Annual Crash Changes		Initial Yr	Design Yr	Initial Yr	Design Yr
Severity	Fatal	0	0	-0.2	-0.3
Category:	Major Injury	0	0	-0.6	-0.9
	Minor Injury	0	0	-5.4	-7.8
	Possible Injury	0	0	-11.1	-16.1
	Property Damage Only	0	0	-26.9	-39.0
Total Injury + Fatal		0	0	-17.3	-25.0
		No Build		290 Freeway Upgrade	
Average Annual Emissions Changes (tons)		Initial Yr	Design Yr	Initial Yr	Design Yr
Emissions	HC	0	0	-83.3	-849.2
(Tons)	CO	0	0	142.4	-484.6
	NOx	0	0	10.8	0.5
	CO_2	0	0	7.9	-775.6
	PM10	0	0	0.0	0.0

Figure 5.4: Output Summary Crashes and Emissions Changes

The final major output summary component shows **travel behavior** and **changes** among the various scenarios. In the initial and design years, the VMT percent splits by each TOD period are noted, as are the percent splits by mode. Total VMT for each scenario in the initial and design year is also reported, as shown in Figure 5.5.

		No Build		290 Freeway Upgrade	
VMT Splits by Time of Day		Initial Yr	Design Yr	Initial Yr	Design Yr
	AM Peak	26.1%	26.1%	26.1%	26.1%
	Mid Day	17.5%	17.5%	17.5%	17.5%
	PM Peak	33.1%	33.1%	33.1%	33.1%
	Evening	11.0%	11.0%	11.0%	11.0%
	Off Peak	6.0%	6.0%	6.0%	6.0%
	Total VMT	5315.6	6142.0	5315.6	6143.6
		No Build		290 Freeway Upgrade	
VMT Splits by Travel Mode		Initial Yr	Design Yr	Initial Yr	Design Yr
	Mode 1	72.5%	72.5%	72.5%	72.5%
	Mode 2	12.7%	12.7%	12.7%	12.7%
	Mode 3	3.2%	3.2%	3.2%	3.2%
	Mode 4	0.2%	0.2%	0.2%	0.2%
	Mode 5	11.3%	11.3%	11.3%	11.3%

Figure 5.5: Output Summary VMT and Splits by Time of Day and Travel Mode

5.2 Summary Charts

In addition to providing numerical results, PET also offers a number summary charts that are automatically created and display graphical results for scenario comparison. To access the summary charts, click the "**Summary Charts**" navigation button. This will load 19 automatically generated charts, such as the one shown in Figure 5.6.
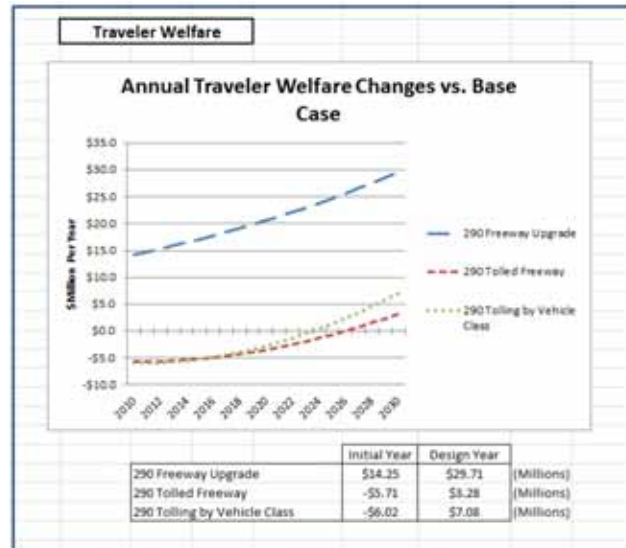
Figure 5.6: Summary Chart for Traveler Welfare

Each chart tracks a given key evaluation measure or impact over time. Some charts display changes of measures in alternative scenarios vs. the base case scenario (e.g., how many more or fewer crashes are predicted for a given alternative relative to the base case scenario), while other charts track the measure itself over time (e.g., how many *total* crashes do we expect each year in each scenario). The initial and design year values for the tracked measures are displayed below the chart for each scenario. The 19 charts that are automatically generated are as follows:

- Annual Traveler Welfare vs. the Base Case Scenario
- Annual Reliability vs. the Base Case Scenario
- Annual Reliability Costs
- Annual Crash Cost Savings vs. the Base Case Scenario
- Annual Crash Costs
- Annual Change in # of Fatal and Injury Crashes vs. the Base Case Scenario
- Annual # of Fatal and Injury Crashes
- Annual Emissions Changes vs. Base Case Scenario
- Annual Emissions Quantities
- Annual Emissions Comparison, Base Case Scenario
- Annual Emissions Comparison, Alternative Scenario 1

- Annual Emissions Comparison, Alternative Scenario 2

- Annual Emissions Comparison, Alternative Scenario 3

- Annual Change in Tolling Revenues vs. Base Case Scenario

- Annual Tolling Revenues

- Annual Change in VMT vs. Base Case Scenario

- Annual VMT

- Annual Change in Fuel Use vs. Base Case Scenario

- Annual Fuel Use

The **emissions charts** display any 3 of the 14 tracked emissions; the analyst chooses which 3 at a time by modifying the Primary, Second, and Third Analysis Emissions selections, as shown in Figure 5.7.

Figure 5.7: Analysis Emissions Settings

The first (Primary) emission species is compared in 1 graph for all 4 scenarios, and then all 3 chosen species (primary, second, and third) are presented together in 4 different charts (for the base case and 3 alternatives). The Annual Emissions Changes vs. Base Case Scenario and the Annual Emissions Quantities charts plot the *single* emission species entered in the Primary Analysis Emission input cell. The Annual Emissions Comparisons charts plot *all three* analysis emissions species in the same chart, for the scenario corresponding to the chart name. This enables the analyst to determine how emissions are changing between scenarios and to assess how various emissions species are changing with respect to other species within a given scenario.

Figure 5.8 shows how one primary emission species is plotted against the base case for up to three scenarios for the same species.
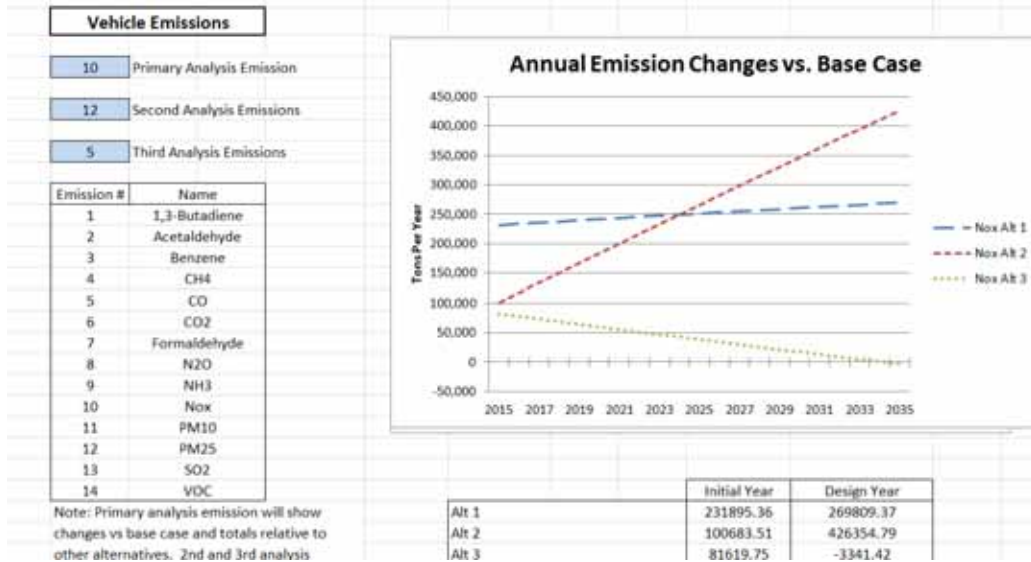
Figure 5.8: Example of emissions plotting for three scenarios

Figure 5.9 shows how primary, second, and third pollutant species are graphed separately, for the base case and alternatives, to gauge changes in one emissions species relative to another entirely different species.
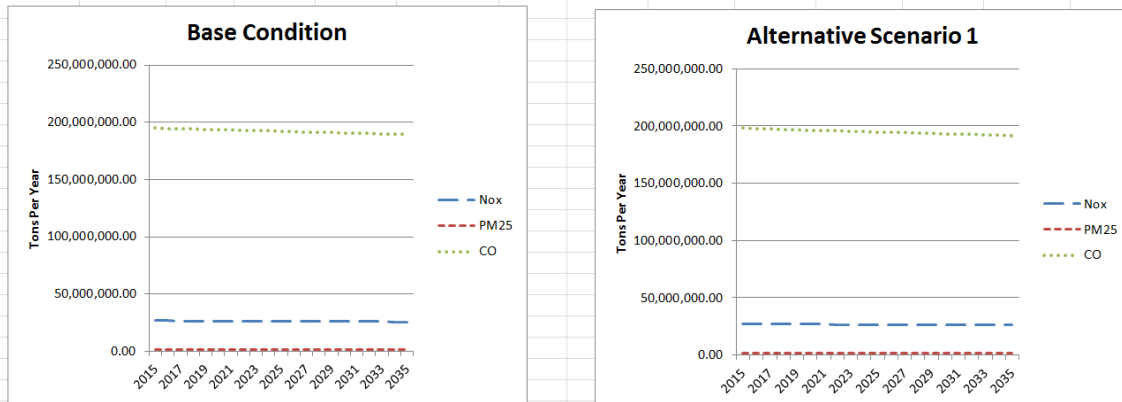
Figure 5.9: Examples of pollutant graphs

The 14 emissions species are numbered as follows:

1. 1,3 - Butadiene (BUTA)

2. Acetaldehyde (ACET)

3. Benzene (BENZ)

4. Methane (CH4)

5. Carbon Monoxide (CO)

6. Carbon Dioxide (CO2)

7. Formaldehyde (FORM)

8. Nitrous Oxide (N2O)

9. Ammonia (NH3)

10. Nitrogen Dioxide (NOx)

11. Particulate Matter < 10 μm (PM 10)

12. Particulate Matter < 2.5 μm (PM 2.5)

13. Sulfur Dioxide (SO2)

14. Volatile Organic Compounds (VOC)

5.3 Traffic Link Comparison

The analyst may also wish to compare the estimated **traffic volumes** and **speeds** between scenarios on certain **links**. The easiest way to do this is to go to the *Link Comparison* sheet, which may be accessed by clicking on the "Link Comparison" navigation button. This will bring up the screen shown in Figure 5.10:

	A	B	C	D	E	F	G	H	I	J	K	L
1					Project Evaluation Toolkit - Link Comparison							
2												
3		Go To Navigation Panel										
4												
5												
6		**Initial Year**							AADT			Average Daily
7		Link #	From Node #	To Node #	Link Name	Length (mi)	Base Case	290 Freeway Upgrade	290 Tolled Freeway	290 Tolling by Vehicle Class	Base Case	290 Freeway Upgrade
8		141	17	19	290: 35 - Dessau / Cameron	0.5	30366	30366	30366	30366	53.2	53.2
9		142	19	17	290: Dessau / Cameron - 35	0.5	31001	31001	31001	31001	53.1	53.1
10		143	19	20	290: Dessau / Cameron - 183	1.3	29499	29499	29499	29499	53.6	53.6
11		144	20	19	290: 183 - Dessau / Cameron	1.3	29499	29499	29499	29499	53.6	53.6
12		145	20	21	290: 183 - Springdale	1.2	20500	20500	18224	18689	35.3	54.8
13		146	21	20	290: Springdale - 183	1.2	20500	20507	18224	18689	35.3	54.8
14		147	21	22	290: Springdale - Harris Branch / Gile	1.9	20500	20513	20500	20501	23.8	54.8

Figure 5.10: Link Comparison

This sheet provides link-specific initial year and design year information for traffic volumes, average speeds, and PM peak speeds (typically the most congested TOD period) for each scenario. Total traffic and estimated speeds are reported, as well as changes between the base case and alternative scenarios.

In order to change the links that the user wishes to examine, the user simply needs to change the values in the **Initial Year Link #** column (the link numbers in the design column will automatically update to match those in the initial year).

5.4 Impact Category Summaries

In certain instances, the user may wish to understand more fully what is occurring with respect to a given impact measure. The **Impact Category summaries** provide the user with this opportunity. The five summary sheets include a traveler welfare summary, a reliability summary, a crash summary, an emissions summary, and a summary for tolls, fuel use, and VMT.

The impact summaries note how the impacts change each year in each scenario, and report an annual growth rate. Total changes between the base case and alternative scenario for the impact category are then assessed. Figure 5.11 illustrates this for travel time reliability.

Project Evaluation Toolkit - Travel Time Reliability Summary

Go To Navigation Panel

Project Design Life: 20 Years
Growth is Exponential

Base Condition	Annual Reliability Costs	
Initial Year Costs	$247.02	(Millions)
Design Year Costs	$652.45	(Millions)
Average Annual Costs	$419.04	(Millions)
Reliability Cost Growth Rate	4.98%	

290 Freeway Upgrade	Annual Reliability Costs	
Initial Year Costs	$239.72	(Millions)
Design Year Costs	$608.02	(Millions)
Average Annual Costs	$397.12	(Millions)
Annual Reliability Benefit	$21.92	(Millions)
Reliability Cost Growth Rate	4.76%	

290 Tolled Freeway	Annual Reliability Costs	
Initial Year Costs	$239.72	(Millions)
Design Year Costs	$613.13	(Millions)
Average Annual Costs	$399.07	(Millions)
Annual Reliability Benefit	$19.97	(Millions)
Reliability Cost Growth Rate	4.81%	

290 Tolling by Vehicle Class	Annual Reliability Costs	
Initial Year Costs	$239.72	(Millions)
Design Year Costs	$607.44	(Millions)
Average Annual Costs	$396.90	(Millions)
Annual Reliability Benefit	$22.14	(Millions)
Reliability Cost Growth Rate	4.76%	

Annual Reliability Costs				
Year	Base Cond	Sc 1	Sc 2	Sc 3
0	$247	$240	$240	$240
1	$259	$251	$251	$251
2	$272	$263	$263	$263
3	$286	$276	$276	$276
4	$300	$289	$289	$289
5	$315	$303	$303	$302
6	$331	$317	$318	$317
7	$347	$332	$333	$332
8	$364	$348	$349	$348
9	$382	$364	$366	$364
10	$401	$382	$383	$382
11	$421	$400	$402	$400
12	$442	$419	$421	$419
13	$464	$439	$441	$439
14	$488	$460	$463	$460
15	$512	$482	$485	$481
16	$537	$505	$508	$504
17	$564	$529	$533	$528
18	$592	$554	$558	$554
19	$622	$580	$585	$580
20	$652	$608	$613	$607

Annual Reliability Benefit				
Year	Base Cond	Sc 1	Sc 2	Sc 3
0	$0	$7	$7	$7
1	$0	$8	$8	$8
2	$0	$9	$9	$9
3	$0	$10	$10	$10
4	$0	$11	$11	$11
5	$0	$12	$12	$12
6	$0	$14	$13	$14
7	$0	$15	$14	$15
8	$0	$16	$15	$17
9	$0	$18	$17	$18
10	$0	$20	$18	$20
11	$0	$21	$20	$22
12	$0	$23	$21	$24
13	$0	$25	$23	$26
14	$0	$28	$25	$28
15	$0	$30	$27	$30
16	$0	$33	$29	$33
17	$0	$35	$31	$36
18	$0	$38	$34	$39
19	$0	$41	$37	$42
20	$0	$44	$39	$45

Figure 5.11: Reliability Summary

The **total annual** reliability **costs** are reported for each year in the middle columns while the **annual** reliability **benefit** (vs. the base case scenario) is assessed for each year in the right columns. On the left, for each year the initial year costs, design year costs, average annual costs, scenario benefit, and growth rate for reliability costs is reported.

This basic format is used to summarize annual changes for all impact categories. However, note that certain summaries have slight variations. Because traveler welfare is estimated in comparison to the base case scenario, no "total traveler welfare" costs are reported. In addition to reporting costs, the expected annual number of crashes (by severity) is reported in the crash summary, as well as the initial and design year crash rate (fatal + injury) per million VMT. The emissions summary reports emissions quantities and changes for all scenarios and species in the initial and design year. The summer daily emissions quantity, the winter daily emissions quantity, and the annual quantity of emissions is reported for each species.

5.5 Individual Scenario Sheets

Some users may wish to understand what PET is estimating at the **individual link level**. This is where PET estimates the actual reliability costs, fuel consumption, tolling revenues, number of crashes, and emissions quantities. Users should be cautioned, however, from reading too much into the individual link-level results. While PET is structured to perform well in the aggregate sense, the **accuracy at the individual link-level contains much greater uncertainty**.

PET has four types of individual scenario sheets: *Volume Output*, *Link Crash*, *Intersection Crash*, and *Emissions Estimate*. Each type of individual scenario sheet has eight sheets—one for each scenario's initial year and one for each scenario's design year.

The *Volume Output* sheets take data directly from the travel demand model in the form of **traveler welfare** and **traffic link volumes**, by time of day, user type, and mode. This information is then used to estimate average **speeds**, **travel times**, **tolling revenues**, **fuel use**, **travel time variance,** and **variance costs** on each link for each time of day. Key scenario summary information is also reported, including total traveler welfare, variance costs, tolling revenues, fuel use, and VMT, as shown in Figure 5.12:

Project Evaluation Toolkit - Traffic Volume Output, Alternative Scenario 1 Initial Year

Go To Navigation Panel

Notes: All links are directional (including # of lanes in each link)

							AM Peak Traffic		% Mid Day Traffic		% PM Peak Traffic		% Evening Traffic		% Off Peak Traffic		
Tot Ann. Traveler Welfare		$14,250,951					26.1%		17.5%		33.1%		11.0%		6.0%		
Total Variance Cost		$239,723,015															
Total Ann. Toll Revenue		$122,045,537															
Total Annual Fuel Use		62,935,194					% Mode 1		% Mode 2		% Mode 3		% Mode 4		% Mode 5		
Annual Million VMT		5,315.56					72.5%		12.7%		3.2%		0.2%		11.3%		

			Link				AM Peak		Mid Day		PM Peak		Evening		Off Peak		
Link #	From Node #	To Node #	Link Name	Link Length	FF Speed	Total Flow Veh/Hr	Avg Speed	Total Flow Veh/Hr	Avg Speed	Total Flow Veh/Hr	Avg Speed	Total Flow Veh/Hr	Avg Speed	Total Flow Veh/Hr	Avg Speed	AADT
1	51	1	183: N of TT45 - TT45	1	55	917	55.0	814	55.0	1178	55.0	398	55.0	144	55.0	16498
2	1	51	183: TT45 - N of TT45	1	55	918	55.0	814	55.0	1178	55.0	398	55.0	144	55.0	16499
3	1	10	183: TT45 Loop 1	7.8	55	4150	44.9	3628	49.4	5329	29.0	1756	54.3	652	55.0	74345
4	10	1	183: Loop 1 - TT 45	7.8	55	3708	48.0	3700	49.1	4799	34.6	1810	54.3	627	55.0	69675
5	10	15	183: Loop 1 - Lamar	2.9	55	2797	53.3	3429	51.0	3795	46.9	1677	54.5	589	55.0	58146
6	15	10	183: Lamar - Loop 1	2.9	55	3047	53.1	3429	51.0	4006	47.1	1677	54.5	547	55.0	60032
7	15	16	183: Lamar - 35	1	55	2506	54.0	3429	51.0	3694	48.2	1677	54.5	565	55.0	55986
8	16	15	183: 35 - Lamar	1	55	2693	53.6	3429	51.0	3684	48.4	1677	54.5	541	55.0	56627

Figure 5.12: Volume Output Individual Scenario Sheet

The *Link Crash* individual scenario sheets estimate the total number of **crashes** per year **by severity** on each traffic link and estimate total crash costs. The *Intersection Crash* individual scenario sheets act similarly for intersections. Again, note that predicting crashes and crash severity at the individual link or intersection level using PET is a *rough estimation process*. PET is not intended to be used to predict that certain traffic links will show a much higher or lower number of crashes than in the base case scenario, unless a specific crash modification factor is applied. Total crash changes are intended to be interpreted in the aggregate.

The *Emissions Estimate* individual scenario sheets estimate **summer daily**, **winter daily**, and **total annual emissions** at the individual link level for 14 different species, then summarize impacts for the scenario. As with crashes, users are cautioned against reading too much into individual link impacts and are encouraged to view the results in aggregate.

5.6 Sensitivity Testing

Users wishing to evaluate results in light of uncertainties may do so by running sensitivity testing scenarios. To do so, the user must have first set parameters properly as noted in Section 2.4 before running the travel demand model. If these parameters were set, the results will be recorded and displayed in the *Sensitivity Testing Results* sheet, which may be accessed by clicking on the "**Sensitivity Testing**" navigation button.

The *Sensitivity Testing* sheet provides users with 64 measures that may be reviewed, including 4 summary project indicators, 30 for the initial year and 30 for the design life year:

- Summary Project Indicators (NPV, B/C Ratio, IRR, PP)

- Tolling Revenues

- Monetary Benefits (Traveler Welfare, Crashes, Emissions, and Reliability)

- Crashes (Total and Fatalities)

- Emissions (14 Species)

- Traffic Volumes (AADT for up to 10 links)

PET provides average values (for example, average value among all sensitivity testing trials of NPV, tolling revenues, or number of crashes for a given scenario) as well as values at +1 and -1 standard deviations from the average for each measure, as shown in Figure 5.13.

Initial Year Traffic Links - AADT	Link Number:		145	Link Number:		146
	Average	+1 S.D.	-1 S.D.	Average	+1 S.D.	-1 S.D.
Base Case (No Build)	21296	25912	16680	22033	27020	17046
290 Freeway Upgrade	21510	24271	18748	21608	24747	18469
290 Tolled Freeway	17031	22389	11673	17058	22263	11853
290 Tolling by Vehicle Class	17920	23337	12503	17903	23216	12591

Figure 5.13: Sensitivity Testing, Estimated Traffic Link Volumes, and Ranges

The actual scenario values for each measure are also reported for each sensitivity testing trial. This information may be used by the analyst to develop histograms to better identify potential ranges of outcomes, as was conducted when developing the chart shown in Figure 5.14.
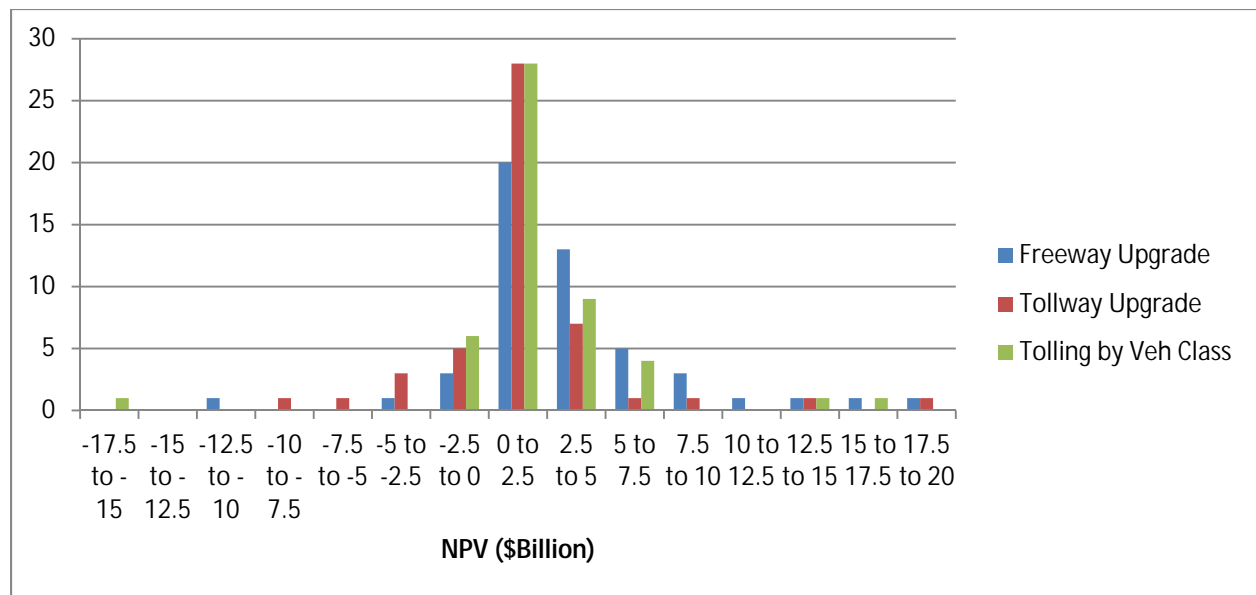
Figure 5.14: Histogram Showing Ranges of Potential Scenario Outcomes

5.7 Operational Strategies

In addition to scenarios evaluated by running the travel demand model, certain "operational strategies" may be evaluated with PET for comparison alongside other scenarios. These strategies allow a user to investigate impacts of advanced traveler information systems (ATIS), incident management, and/or speed harmonization projects on specified network links. The primary benefit of **speed harmonization** is a **reduction in crashes** at peak times, while the primary benefits of **ATIS and incident management** strategies come from **travel time savings**. **Emissions** changes are also reported for **incident management** strategies (due to reduced times that vehicles will be traveling at slower speeds).

User inputs for these three operational strategies are found within their respective sheets, and these can be accessed via the **Navigation Panel**, within the **Project Inputs** column. Output summaries are provided alongside basic alternative scenarios, which include estimated project costs, initial and design year benefits, and summary measures including NPV, B/C Ratios, IRR, and PP. Changes in **crashes** are reported for the speed harmonization strategy and **emissions** changes are reported for the incident management strategy. ATIS, incident management, and speed harmonization, however, do not report the full range of outputs that are shown in the travel demand model.

No emissions changes are reported for ATIS strategies, since too much uncertainty is associated with the additional length of longer routes, delays imposed on other travelers (on alternate routes), operating speeds along the alternate routes, alternate-route facility types, and other required data for estimating emissions. These items are not a concern for incident management strategies because PET assumes that incident management reduces the duration of the incident, thus lessening the amount of time traveled at lower speeds, rather than rerouting vehicles or changing travel patterns, as is the intent of ATIS strategies.

Chapter 6. Evaluating Others' Travel Demand Model Outputs: Using the Back End of PET

Although PET includes its own travel demand model (TDM) to analyze networks of up to 300 links, many modelers already have a TDM for their region and may prefer to estimate **traveler welfare, crashes, reliability, and emissions** impacts using **their own TDM outputs** for their **more detailed networks**. Users with proper link-level output from a TDM can upload their data into PET for quick project evaluation and comparison in aspects not considered outside of extensive evaluations. The following methodology describes how users can evaluate link-level traffic projections in PET without running the included PET TDM for smaller networks.

Users must import **network files** for the base case and at least one alternative for both **initial and design years**. As discussed in Section 6.1, these files include a link number, from-node and to-node data, link length, link capacity, area type (urban/rural), link classification, and number of lanes. Also required are **volume** files (which also must contain link-speeds for each time of day) and **origin-destination** (O-D) files for the base case and one alternative, and for initial and design years as well. Network and volume files are required for crash, emissions, and reliability estimations and O-D files are further necessary to compute traveler welfare as described in Section 10.1. Users may optionally import toll rate files, which are considered for traveler welfare calculations.

To evaluate an external travel demand model's outputs in PET, users must first **format their data** for uploading into PET (see Appendix D). Import features have been created in the Toolkit that will automatically import text files to the appropriate fields, provided text files are formatted properly by the user. External TDM can be imported from PET's *Home* sheet, via the **External TDM Upload Procedure** table on the bottom left of the worksheet, as shown in Figure 6.1. Users may import properly formatted files (as described in the following sections) by first specifying whether to import each particular file; they do this by filling the appropriate cell with a 1 or 0, and clicking the "**Import External TDM Data" macro button**.

Figure 6.1: External TDM Upload Procedure.

Importing files into PET requires some processing time, especially if many links are imported. The upper limit of rows available for import of external TDM data is 300,000. PET processes this data 300 links at a time and can take up to **one minute** to import and compute data for **each set of 300**. Thus, for a data set of 20,000 links, it may take PET about an hour to import, process, and compute final results. The status bar shown in Figure 6.1 indicates the current progress of the import and computation process to provide user feedback through the process.

Users must also set the cell next to "**Use External TDM Outputs (1/0)**" in the General Project Information area of the *Summary Input Information* sheet to "**1.**" This setting informs PET to use the external TDM results when reporting summary results, rather than results obtained from the 300 or fewer links that may be currently loaded into PET's network files.

If all data has been imported properly, **results** can be analyzed in the *TDM Summary* sheet, located under the Project Impact Summaries column for the *Navigation* sheet. The *TDM Summary* sheet provides **monetary impacts** (traveler welfare, reliability, crash costs, and emissions cost), crash data (total, fatal, and injurious), **annual emissions** for 14 species, **and other impacts** (e.g., toll revenues, fuel consumption, and VMT) for the base case and each alternative, for both initial and design years. These results are presented in two formats: (1) **Change vs. Base Case**, for quick relative analysis of alternatives, and (2) **System Impacts**, which shows total impacts for all scenarios. Figure 6.2 shows the *TDM Summary* sheet, with data for Change vs. Base Case outputs.

Go To Navigation Panel								

Change vs. Base Case		Initial Year				Design Year		
	Base Case (No Build)	Alt 1	Alt 2	Alt 3	Base Case (No Build)	Alt 1	Alt 2	Alt 3
Monetary Impacts								
Traveler Welfare	$0	-$586,509	-$587,422	-$586,296	$0	-$444,251	-$445,163	-$444,7(
Reliability	$0	$274,965,600	$298,745,100	-$1,312,518,000	$0	-$1,024,477,600	$442,454,300	-$638,188,0(
Crash Cost	$0	$1,679,900	$2,211,700	$923,353,800	$0	$2,270,700	$2,940,400	$917,887,1(
Emissions Cost	$0	$37,510,700	$28,246,100	$26,010,000	$0	$18,562,400	$31,152,200	-$852,5(
Crashes								
Total	0	19	25	223	0	25	33	1:
Fatal	0	0	0	135	0	0	0	1:
Fatal + Injury	0	8	10	-322	0	10	13	-3(
Annual Emissions (Tons)								
1,3-Butadiene	0	2	2	2	0	1	2	
Acetaldehyde	0	6	5	5	0	3	5	
Benzene	0	13	10	9	0	6	11	
CH4	0	25	19	18	0	13	22	
CO	0	7,731	4,787	4,610	0	5,885	9,684	1!
CO2	0	1,618,294	1,107,619	1,005,935	0	1,022,167	1,694,327	-34,8(
Formaldehyde	0	8	7	6	0	3	6	
N2O	0	26	21	20	0	9	15	
NH3	0	84	53	46	0	64	104	
Nox	0	635	276	224	0	739	1,168	
PM10	0	317	259	235	0	114	199	-:
PM25	0	113	89	82	0	48	82	
SO2	0	31	21	19	0	20	33	
VOC	0	850	671	631	0	352	605	-:
Other Impacts								
Tolling Revenues	$0	-$5,377,495,300	-$5,375,490,100	-$2,607,469,200	$0	-$5,394,663,000	-$5,392,613,100	-$2,615,672,4(

Figure 6.2: TDM Summary Sheet Output for External TDM Data

Other results (such as net present values, benefit-cost ratios, and project financing measures) may be found in the *Output Summary* sheet, the *Impact Summary* sheets, and the *Summary Charts*, as described in Sections 5.1, 5.2, and 5.4, respectively. To ensure external TDM data is imported properly into PET, users *must follow naming and formatting conventions exactly*. These are presented in detail in Appendix D.

Chapter 7. Network Visualization

To help create and keep track of network nodes and links, users can utilize the visualization module, accessed by navigation to PET's *Visualization* sheet. Freely available Google Earth software is the recommended program for users, and can be downloaded from www.googleearth.com. For users without access or license to this product, substitute software may be used, as discussed in Section 7.3.

7.1 Creating Nodes in Google Earth (GE)

In order to create a network for use in PET, users must designate nodes and identify links between these nodes. Users can visually determine nodes easily within Google Earth (GE) and save their work for future use or alterations. The following steps describe the creation of a file in GE that will help users keep track of their networks.

1. **Insert "placemark"** directly on top of one of GE's high-resolution satellite maps at location of interest—for example, the intersection of two major freeways. Simply click on the **yellow pushpin icon** in the toolbar directly above the map area and move to desired location. Make sure the placemarks are stored under the "**My Places**" directory in the "Places" window to the upper left of the map window.

2. **Change name** of placemark to the desired **node number.** Be sure that the network contains **sequential node numbers**; failing to number sequentially may result in errors when running the travel demand model.

3. **Save** the file as **"Coordinates.kml"** in the main **PET directory**.

Figure 7.1 shows an example of nodes created for the Austin network.
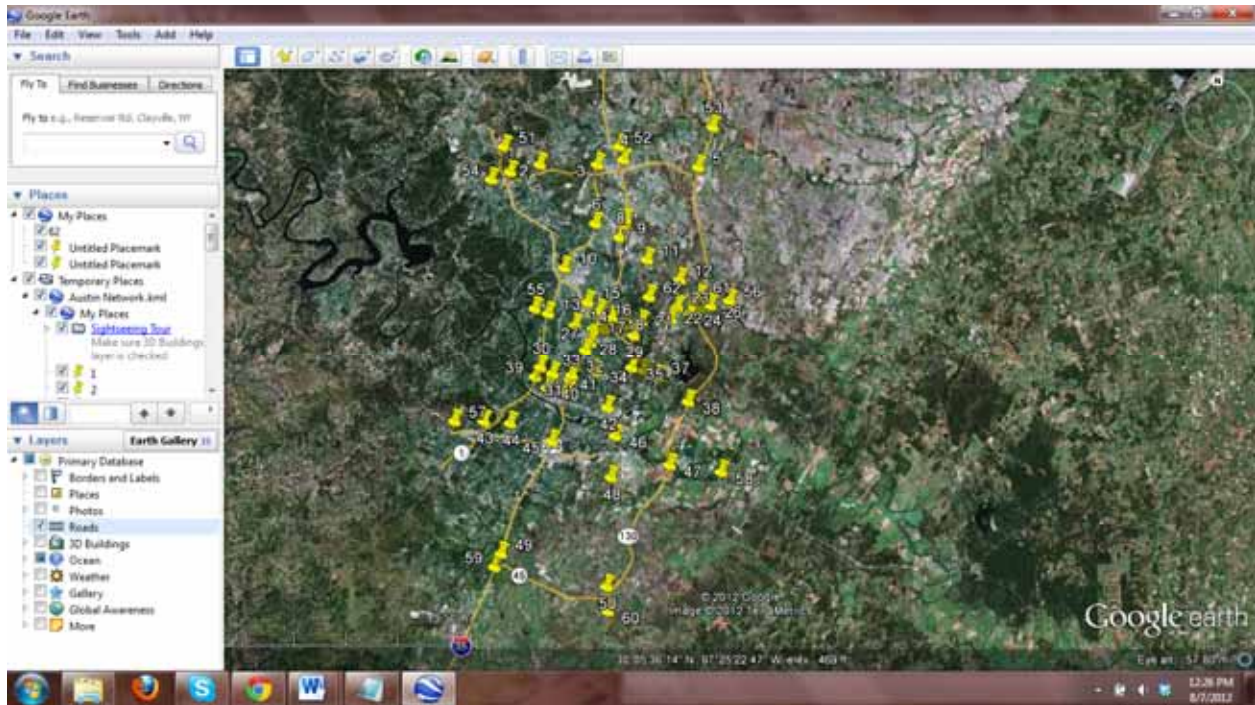
Figure 7.1: Creating Nodes for Austin's 62-Node Abstracted Network.

7.2 Importing Coordinates into PET

Once the KML file is saved, it can be opened any time in GE for editing or viewing. The KML contains coordinates information and node numbers for each placemark. These coordinates can be imported into PET through the *Visualization* sheet by clicking the "Import Coordinates" macro button, as shown in Figure 7.2. PET will automatically extract node coordinates from the "Coordinates.kml" file saved in the PET main directory.

Figure 7.2: Importing Coordinates from Google Earth KML to PET

Alternatively, users can directly input node-specific latitude and longitude values (in either decimal or degrees format) in the *Visualization* sheet. Providing these coordinates is required to create a final visualization of nodes and links, discussed in the following section.

7.3 Creating a Final Visualization File (Nodes and Links)

Users may have already created a KML file with nodes, but PET can create a final KML file that connects each node with links, as specified by node connections in the *Base Highway Link* sheet. Before a network can be visualized coherently with node-to-node links, users must ensure that the network has already been properly defined (i.e., each desired **node-to-node connection** has been specified in the *Base Highway Link Configuration* sheet) as described in Section 2.6. As long as a PET network is defined by a set of links and nodes, and the nodes contain latitudes and longitudes, PET can create a new/second KML file for direct use by GE, with the push of button. By pressing the "**Create KML" button** in PET's *Visualization* sheet, shown in Figure 7.3, a new file named **"Network.kml"** is automatically **generated** and saved in the **main PET directory**.

Figure 7.3: Creating a Final KML File in PET

This file can be opened directly in GE for immediate inspection; GE opens up KML files and loads their map details instantly. The KML file will display all nodes with corresponding number in white, and display all links, in red. Figure 7.4 shows a KML file for the Austin network.
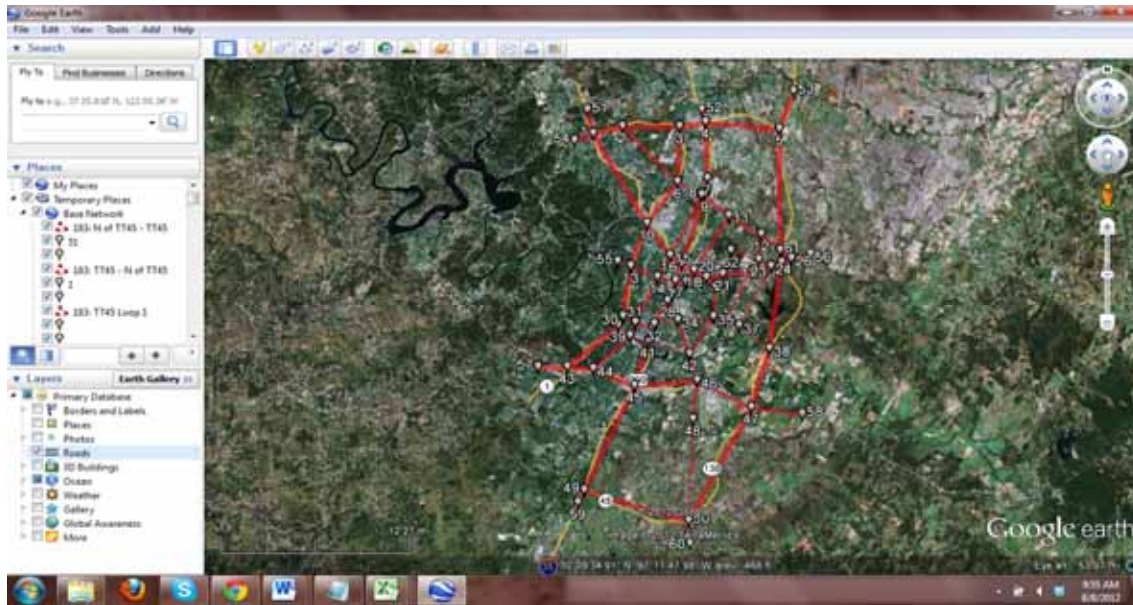
Figure 7.4: Example of Final Output (Network.kml) for Austin Network

The GE map line thickness corresponds to functional classification, with the thickest being higher speed freeway links and the thinnest being minor arterials. The left-hand menu under GE's "Places" directory indicates all nodes and links, and allows users to identify and locate specific links. Double-clicking a feature (e.g., a link or node) from the left-hand menu zooms the map-view to that feature. If two directional links serve a node pair (e.g., one northbound and one southbound), deselecting one of the links helps show that both links exist. GE also allows a layering of roads, places, and other useful features that can help verify node and link locations. Any changes made to this KML will not be imported back to PET. However, as changes are made in PET, KML files can be regenerated. Since PET networks must remain constant between scenarios (i.e., PET protocols require that all alternatives have the same number of links), mapping multiple scenarios (i.e., a base case network and up to three alternatives) presents no advantage. However, users can rely on GE's many mapping tools to highlight key routes for analysis. For instance, users may change the color and size of key links simply by right-clicking a feature from the left-hand menu and adjusting its "Properties" via the "Style/Color" tab.

7.4 Accessing and Editing KML Files outside of Google Earth Software

Outside of GE, Google Maps (accessed from any browser) is the best tool to view a KML file, as created by PET. While the Visualization module does not support importing Google Maps files and does not offer guidance for this, users may produce final KML files (with nodes and links) for viewing in Google Maps with little difficulty. The easiest approach is navigating to "maps.google.com," selecting "My Places," then "Create Map," and selecting "Import." From here, users can simply select the appropriate KML from their computer's directory and upload to the browser. Unfortunately, Google Maps will display only around 200 distinct points (either nodes or links) per page, so the map may be split across multiple pages for larger networks. To avoid this, users can host the file directly to a publicly accessible location and load into the Google Maps search bar. Users may use free hosting sites that include direct links to their files or their personal websites to save KML files. The direct link (e.g., http://k004.kiwi6.com/hotlink/

vbphhbq539/base_viz.kml) can be pasted into the Maps search bar, as highlighted in Figure 7.5, and Google Maps will directly load all points into the map.
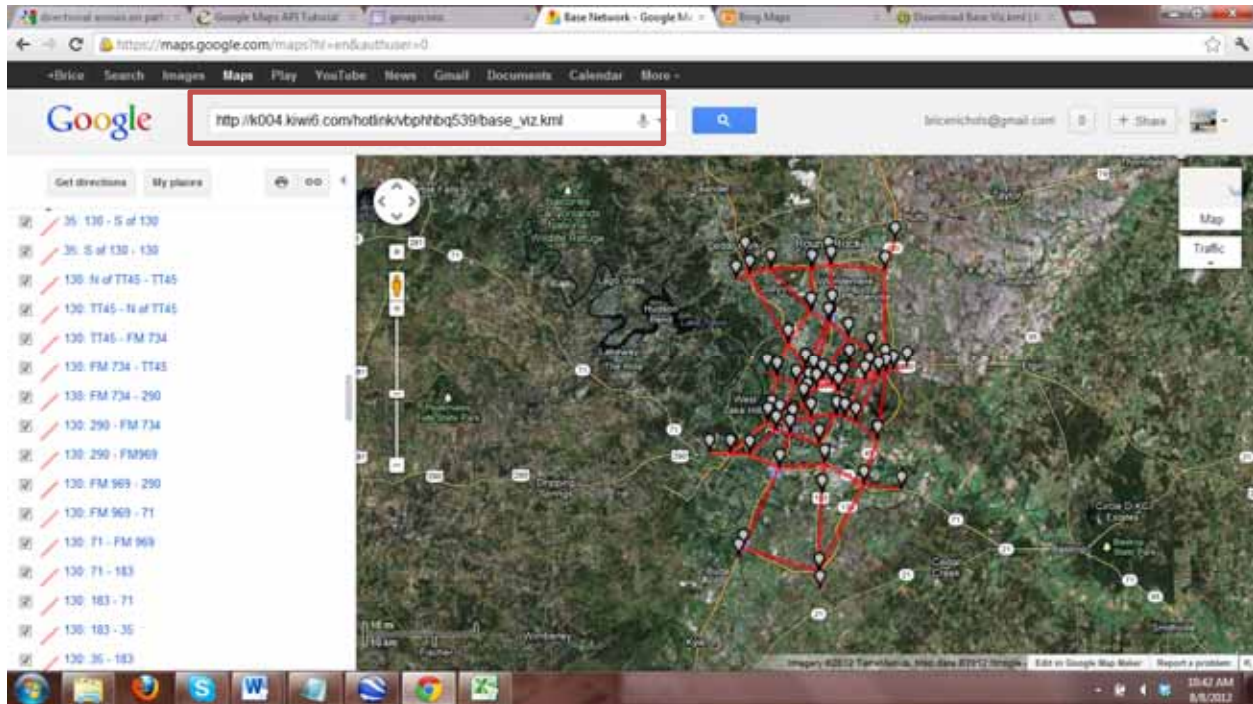
Figure 7.5: Austin KML Loaded to Google Maps with Direct Hotlink

While this approach is less convenient than opening KML files in GE, it provides a work-around solution for those who, for whatever reason, may not be able to use GE (though GE is a freely downloadable and rather small—it requires less than 100 MB for the entire program).

Similarly, if conflicts with Google products arise, users may find some compatibility with Microsoft Bing's browser. Similar to Google Maps, users may upload a KML file directly, with limitations on how many points can be shown. For Bing maps, users select "My Places" and "Import" to load a KML file. However, users must have a (free) Microsoft account to proceed. Figure 7.6 shows the Austin network, only partially imported due to size limitations.
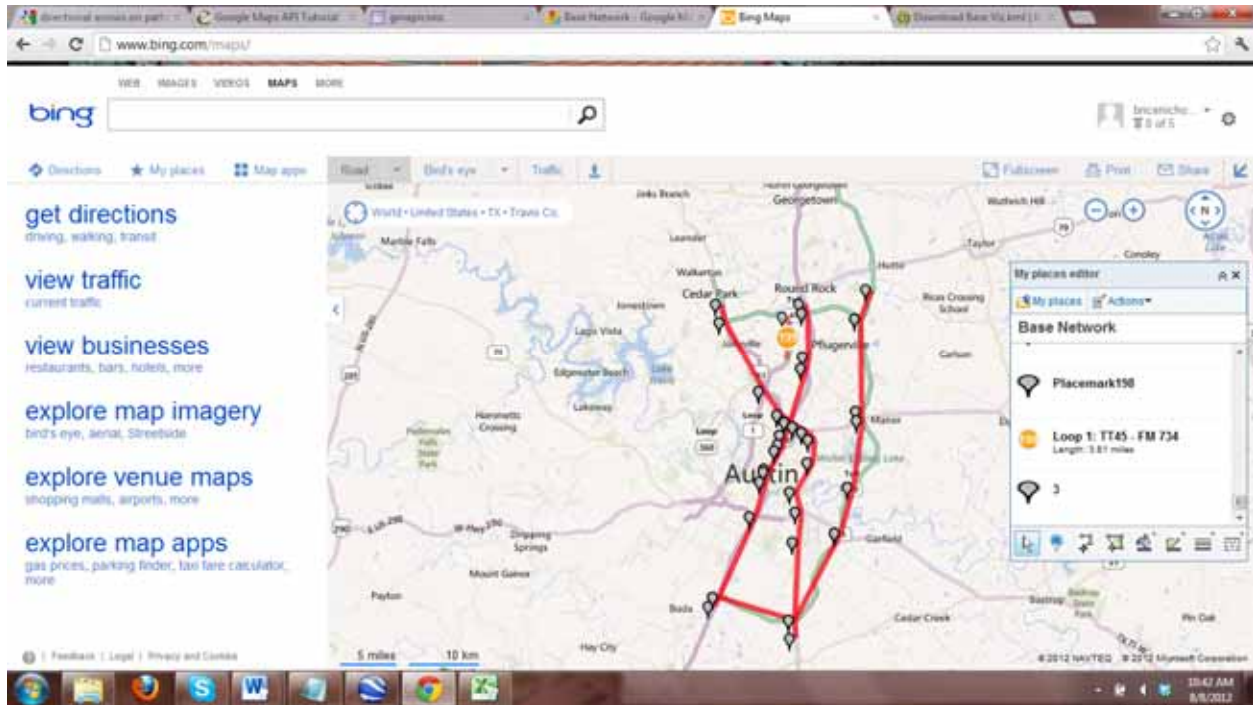
Figure 7.6: Austin KML shown in Microsoft Bing Map, with Limited Capabilities

Users may be able to, with the addition of software packages or coding knowledge, translate KML data to other XML-based languages, like GeoRSS, which can be used to import full files for Bing maps. Similarly, KML data can be converted to "shapefile" format for use with ESRI products like ArcGIS, or their browser-based mapping services, though this is not directly supported as part of the Visualization module. Since Google products provide the most widely used and easily accessible mapping services that can communicate best with PET, their mapping software packages (GE and Maps) are the recommended products to use with PET's new Visualization component.

PART 2: UNDERSTANDING THE TOOLKIT

Part 1 focused on how users can develop a network, run various alternative scenarios, and interpret results in order to assist planning and policy making decisions. Part 2 focuses on **how PET operates** and the various **assumptions** that PET makes in order to arrive at the estimated results. Users are highly encouraged to familiarize themselves with Part 2 in order to fully comprehend the results and understand PET's capabilities and shortcomings.

Chapter 8. Toolkit Structure

PET is a spreadsheet-based **sketch planning tool** for anticipating traffic changes to and evaluating the effects of a variety of transportation network improvements. PET enables quick response by transportation engineers and planners for comparing the effects of adding new roadways and capacity, alongside proposals for tolling schedules, reversible lanes, ramp metering, advanced traveler information systems, rapid incident response, and other strategies.

Thanks to its **spreadsheet-based interface**, PET is user-friendly and can be quickly mastered—and then successfully applied—by those familiar with Microsoft Excel, network attributes, traffic terminology, and project details. Moreover, its evaluation functions and parameters can be conveniently tailored or even replaced by users (within the spreadsheet interface). A unique feature of PET is that it contains a **travel demand estimation module**. This self-contained module allows PET to run as a stand-alone package, providing users with a complete solution for sketch planning and project evaluation (versus a user-defined base case scenario) without resorting to any other software tools and subject to their limitations. Use of Microsoft Excel as its software platform is also appealing to users due to the powerful data manipulation capabilities provided by Excel, allowing users to exploit Excel's rich embedded numerical commands, statistical functions, and visualization abilities to process and analyze—and extend—input and output data sets.

Estimation of traffic flow patterns in a multi-modal, multi-period network under different network scenarios is PET's most computationally demanding task. For this reason, PET's travel demand estimation module is coded in the computationally efficient and fast-running C++ language and compiled as external executable programs to be accessed by the spreadsheet application. The data communication function between the Excel spreadsheet interface and the C++ executable programs is established by a group of spreadsheet-embedded VBA scripts. This modular design results in at least three advantages:

1. The most computationally intensive functions are programmed in C++, reducing computational bottlenecks to the maximum extent, while the interface is fully contained in Excel spreadsheets, which will be intuitive for and widely accepted by PET's expected users;

2. The external C++ programs for travel demand estimation can be run independently without PET's spreadsheet interface, enabling advanced users to directly manipulate, test, and diagnose the computational process of the travel demand modeling module and analyze its results; and

3. In case another program or process for travel demand estimation is preferred (by a metropolitan planning organization such as the North Central Texas Council of Governments, for example), its outputs can be conveniently provided as inputs via a separate module without intensively modifying PET's existing structure and other modules.

In terms of this last item, the possible modification lies only in the VBA scripts: they may need to be modified so as to properly read and write the input and output data files for the new travel demand estimation module.

Figure 8.1 illustrates PET's software structure, as described above, with the following software components:

- **C++ programs**: Travel demand estimation module

- **Microsoft Excel spreadsheets**: Other functional modules and data storage, manipulation, visualization environment

- **VBA macros**: Data and parameter communication between the Excel spreadsheets and C++ programs and sensitivity testing

The **modular design** facilitates extension of PET's functionality, and PET developers have extended the original version (designed initially for evaluating strategic network expansions) to the new version, which can be used to evaluate various operational network improvements, including shoulder lane use (SLU), speed harmonization (SH, also known as variable speed limits), ramp metering (RM), signalization changes, managed lane applications (ML), incident management/incident response time changes (IM), and advance traveler information systems (ATIS). Evaluations of some of the operational strategies (SLU, RM, signalization changes, and ML) involve changing the transportation network characteristics and running the travel demand module, while remaining strategies (ATIS, SH, and IM) can be evaluated by running the travel demand model for the base case (no-build) scenario only, and configuring the appropriate operational strategy to assess the anticipated impacts.
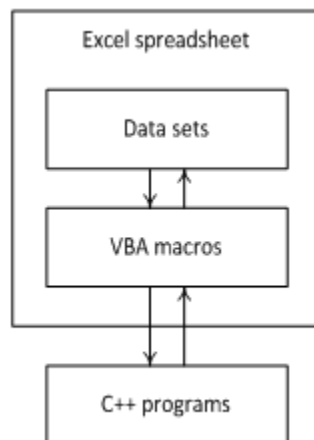
Figure 8.1: Software Structure of the Sketch Planning Toolkit

Chapter 9. Travel Demand Model Operation

PET's **travel demand forecasting module** is a key component and functional basis for performing subsequent project analysis and evaluation tasks in other functional modules. The module is designed to closely mimic large, full-size network demand estimation results across different roadway facilities, times of day, and changed network conditions, while reducing computing times, data demands, and staff expertise requirements.

PET's travel demand model uses five major steps to **assign traffic flows** among transportation **modes**, across **time of day** (TOD) periods, and **over the network**. These produce a base trip table estimate, elastic trip table estimates for each scenario, mode split and TOD estimates, and link-based traffic assignments (for each traveler class modeled). Once the traffic assignment process is complete, the model checks for convergence (using traffic flow stability as described later) and loops back to the elastic trip table estimation process if convergence has not been reached, as shown in Figure 9.1.
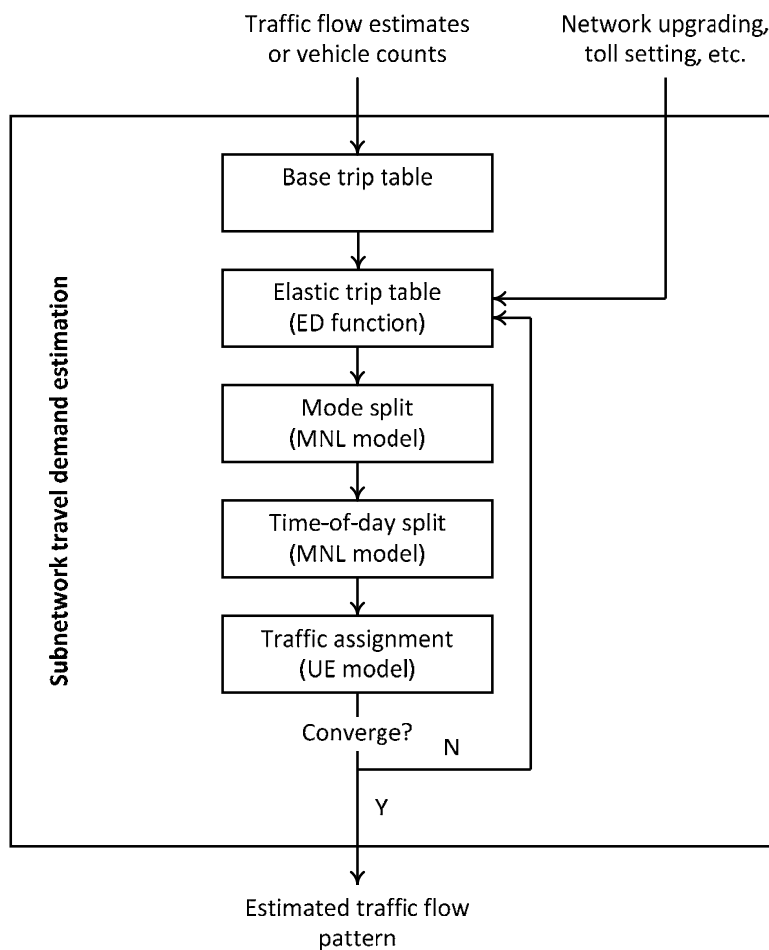
Figure 9.1: The Travel Demand Modeling Process

The first step's estimate of the origin-destination (O-D) **trip table** uses a "target" trip table and applies a least-squares approach to approximate both the target trip table and the link volumes simultaneously. This target trip table is obtained through a simple gravity model, but the method is "modular" and another methodology for generating the target trip table is easily accommodated. A stochastic user equilibrium (SUE) approach is used to decide which links will be used by the demand between two nodes. The code returns this trip table, as well as the SUE logit parameter that fits the link counts best. Details on formulation and algorithms for this process can be found in Appendix E.

The second step uses an **elastic demand function** to estimate cost-dependent O-D trip rates for all other scenarios, by pivoting off of the base-case trip rates using an assumed demand elasticity for each time of day (e.g., by default, -0.69 for all periods).

The third step, **mode split**, uses an incremental multinomial logit (MNL) model (Ben-Akiva and Lerman, 1985) to distribute the O-D trips (as developed in the second step) into different transportation modes, such as drive-alone, shared-ride modes, transit, and non-motorized modes.

The fourth step also uses an incremental MNL model to produce trip tables by **time of day** for each transportation mode. The fifth step assigns these various trip tables (by vehicle type, traveler class, travel mode, and time of day) to the abstracted/coded network under the user-equilibrium principle.

The fifth step, a multi-class, multi-mode **traffic assignment** problem, is also performed using the Frank-Wolfe algorithm, but in a modified version. The all-or-nothing traffic loading during the above Frank-Wolfe procedure is achieved using the Floyd-Warshall algorithm (Floyd, 1962), which is the most efficient method for finding all-to-all shortest paths over a network, because most of the nodes in network cases to which PET is applied are both origin and destination nodes.

Note that the last four steps form a supply-demand interaction loop and are conducted iteratively, so that computations of trip shares in the second, third, and fourth steps are consistent with the time-and-cost outputs of the fifth step. In other words, supply-demand interactions are treated with "full feedback" (rather than just equilibrating travel times and costs in the fifth step, across routes, leaving trip tables fixed).

While the first step involves a one-time, trip table estimation event for the base-case condition, all other steps are part of the **iterative process** with a **feedback mechanism**, to ensure that flows and costs are in equilibrium, between different times of day, across transportation modes, and across network routes. The feedback process iterates over the last four steps until the consistency between traffic flows and travel costs are reached (such that the gap between successive flow estimates is sufficiently low). The convergence of the last steps is achieved by the method of successive averages (MSA).

The major structural difference between PET's travel demand modeling process and the traditional four-step process lies in trip generation and distribution. PET generates an O-D trip

table entirely based on observed traffic counts, while the traditional process estimates trip productions and attractions from land use and socioeconomic data in the investigated region.

The travel demand estimation module is coded in C++ and complied into two executable programs: *tdm_matrix.exe* and *tdm_flow.exe*. The first program computes the base trip table estimation, while the second program performs the last four steps of the travel demand estimation process.

Given the modular nature of PET's software structure, the travel demand estimation module must have its own **input and output functions** so as to communicate with the other parts of the toolkit. These functions are referred to as the input and output submodules for the *tdm_matrix.exe* and *tdm_flow.exe* programs. The input submodule for the *tdm_matrix.exe* program is relatively simple, reading in the network file and link flow rate file for each TOD period; the output submodule for the *tdm_matrix.exe* program outputs the O-D trip table for each TOD period. The input submodule for the *tdm_flow.exe* program reads four groups of data files, including the original and alternative network files, base O-D trip table files, growth factor file, and parameter file. The output submodule for the *tdm_matrix.exe* program includes the link flow rate files, elastic trip table files, and network summary file. The network summary file provides the network-wide performance measures resulting from the travel demand estimation process, such as traveler welfare change, total travel cost, vehicle hours traveled (VHT), and vehicle miles travelers (VMT).

Chapter 10. Project Impact Estimation

Project impacts are estimated for **traveler welfare**, **travel time reliability**, **crashes,** and **emissions**, as well as other metrics such as total system **VMT**, **fuel use,** and **tolling revenues**. For each of these measures, impacts are assumed to grow exponentially for all years in between the initial year and the design year. That is, PET estimates the growth rate that needs to occur in order for the value in the initial year to reach the value in the design year. Thus, if 20 crashes are estimated in the initial year and 50 in the design year, the crash growth rate would be estimated at 4.69%, assuming an analysis period of 20 years. Therefore, each year of the analysis would be estimated to have 4.69% more crashes than the previous one. A graphical depiction of this is shown in Figure 10.1:
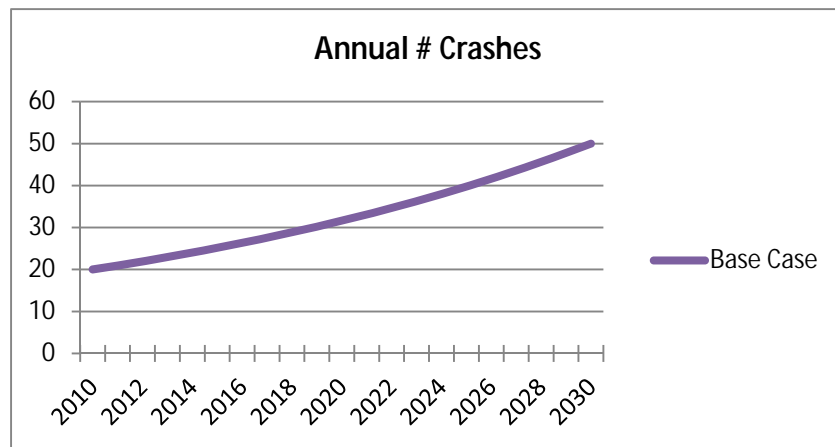
Figure 10.1: Illustrative Depiction of Changes in Crashes over Time

The one **exception** to this rule is if **traveler welfare** is negative in the initial year and positive in the design year, or vice versa. Total scenario reliability costs, crashes, emissions, fuel use, VMT, and tolling revenues must be positive. Traveler welfare, however, is measured against the base case scenario and may therefore be positive or negative. If traveler welfare has opposite signs for a given scenario's initial and design years, no growth rate will achieve a change in sign, as even a highly negative growth rate will cause the measure to approach zero, but not change sign. Therefore, PET assumes a quadratic profile if traveler welfare signs in the initial and design years are different. This takes the form shown in Equation 10.1:

$$TW_y = TW_{IY} + \frac{y^2(TW_{DY} - TW_{IY})}{ProjLife} \tag{10.1}$$

where TW_y is the value of traveler welfare in year y, IY is the initial year, DY is the design year, and *ProjLife* is the project design life. This results in a profile similar to the exponential form, as shown in Figure 10.2:

Annual Traveler Welfare Changes vs. Base Case
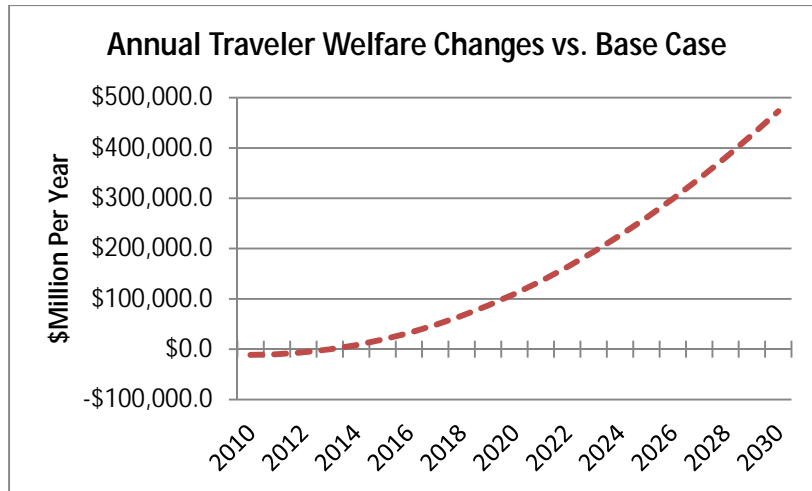
Figure 10.2: Illustrative Depiction of the Quadratic Function for Traveler Welfare Estimation

10.1 Traveler Welfare Evaluation

Traveler welfare is estimated as a function of **monetized travel time changes** and **operating costs**, while accounting for benefits to new travelers between each origin-destination pair due to reduced costs, or disbenefits to prior travelers who no longer travel between the origin-destination pair due to increased costs. Various user classes are assumed to have different values of time and *Mode 5* is assumed to be heavy-duty vehicles, which are assumed to take up more link capacity than other vehicle types.

Travel speed s_a on link a is calculated by the widely used Bureau of Public Roads (BPR) function, as in the TRB's Highway Capacity Manual (2000). This function takes the following form shown in Equation 10.2:

$$s_a = s_a^0 \left(\frac{1}{1+\alpha \left(\frac{v_a}{c_a} \right)^\beta} \right) \tag{10.2}$$

where s_a^0 is the link's free-flow speed, v_a/c_a is the link's volume-capacity ratio, and α and β are behavioral parameters. Default α and β values for freeway speed estimates were obtained from Martin and McGuckin (1998), those for arterials were obtained from the Highway Capacity Manual (TRB, 2000), and those for collectors, local roads, and ramps were obtained from Jeihani et al. (2006). Arterials were assumed to be Class I arterials with 0.6 mile signal spacing when determining default link performance function arterial parameters. Default free-flow speeds were obtained from Cambridge Systematics (2008).

Individual **value of travel times** (VOTTs) vary widely, depending on where and how the data are collected, and who the targeted travelers are. For example, Brownstone and Small (2005) estimated the VOTT using revealed-preference data along Southern California's SR-91 to be nearly two times that emerging from stated preference surveys. Furthermore, because the value of travel savings typically is tied to wealth and wage rates, high-income individuals regularly exhibit VOTTs higher than lower-income individuals. To recognize traveler heterogeneity, PET

permits up to five traveler types (for demand pattern estimates as well as traffic assignment/route choice). Such variety can be especially important when anticipating the impacts of tolling policies. (For example, congestion pricing has more favorable welfare results when VOTTs vary [Small and Yan, 2001; Verhoef and Small, 1999].) The following paragraph discusses research findings that PET users may utilize when examining ranges during sensitivity testing.

Levinson and Smalkoski (2003) estimated heavy-duty truck VOTTs in the US to average $49.42 per hour. Brownstone and Small (2005) estimated those of morning commuters in the Los Angeles area along routes SR 95 and IH 15 to generally lie between $20 and $40 per hour, using revealed preference techniques. They also estimated values of reliability (VOR) to be $12 to $32 per hour of standard deviation in arrival time, or roughly 95 to 145% of the corresponding VOTT on those links. The Oregon DOT (2006) estimated VOTTs of $16.31 per hour for autos, $20.35 per hour for light trucks, and $29.50 per hour for heavy trucks. Schrank and Lomax (2009) used $15.47 per hour for autos and $102 per hour for commercial vehicles. Litman (2009) recommends that paid travel be valued at 150% of the wage rate, commuting and congested travel be valued at 50% of the wage rate for drivers and 35% for passengers, uncongested travel be valued at 25% of the wage rate, and pleasurable travel be valued at $0, with a range of $10.20 to $15.60 per hour of standard deviation in arrival time for the value of reliability. Zamparini and Reggiani (2007) conducted a meta-analysis of VOTTs and estimated an average of 82% of the wage rate, with an average of 68% for North American travelers. Furthermore, they estimated time valuations at 55% of the wage rate for commuting, 146% for employer's business, and 60% for other activities.

PET uses a **default** of 5% heavy vehicle commercial traffic (Davis and Diegel 2007) with **value of travel time** valued at $50 per hour. An average wage rate of $18.85 is assumed (BLS, 2010), which is rounded up to $20 per hour for default calculations. Of the remaining 95% of VMT, 10% is assumed to be work related, valued at $30 per hour; 20% is assumed to be commuting, valued at $10 per hour; and the remaining 65% is assumed to be general purpose errand or social/recreational, valued at $5 per hour.

Vehicle **operating costs** also vary across sources. The American Automobile Association (AAA) estimates a cost of $0.47 to $0.72 cents per mile for a sedan, with a base cost of $0.179 per mile for gas and maintenance and other costs for insurance, licensing, financing, and registration (AAA, 2008). Polzin et al. (2008) estimated operating costs at $0.21 per mile. Barnes and Langworthy (2003) estimated these at $0.173 per passenger-car mile, $0.217 per pickup truck, van or SUV mile, and $0.49 per commercial-truck mile. To reflect operating costs, PET uses a **default operating costs** of $0.50 per mile for commercial vehicles and $0.20 per mile for all other vehicles. Of course, high-fuel-economy vehicles will pay less, while gas guzzlers and others with operating issues will pay more. And, of course, all defaults in PET are changeable by the user.

The travel demand forecasting module estimates traveler welfare benefits of each project scenario (vs. the no-build base case). These changes in traveler welfare are a function of **travel times** (and thus link speeds and traffic volumes) and **direct user costs** (such as operating costs and tolls). Traveler welfare estimates are evaluated by O-D pair: when demand is elastic (i.e.,

travelers can choose different times of day, modes, and destinations), the economic value of complete trips cannot be captured at the link level.

The traveler welfare (sometimes referred to as *consumer surplus*) changes are approximated using the popular **rule-of-half** (RoH) method (which assumes linear demand curves between O-D pairs, and is quite reasonable in the presence of non-linear response for relatively moderate changes in network performance). For each O-D pair r-s, TOD period d, and traveler class k, the consumer surplus change approximated by RoH is represented in Equation 10.3:

$$TW_{ij,d}^{k} \cong \frac{1}{2}\left(w_{ij}^{b,k}x_{ij,d}^{b,k} + w_{ij}^{k}x_{ij,d}^{k}\right)\left(g_{ij,d}^{b,k} - g_{ij,d}^{k}\right) + w_{ij}^{b,k}x_{ij,d}^{b,k}\left(g_{ij,d}^{b,k} - g_{ij,d}^{k}\right) \qquad (10.3)$$

where x is the O-D flow rate, g is the O-D generalized travel cost, and w is the vehicle occupancy rate. As shown in Figure 10.3, the benefit to users equals the shaded areas, in which the first and second terms of the above function represents areas 1 and 2, respectively. The above traveler welfare change values are summed over all traveler classes, all O-D pairs, and all TOD periods, to properly reflect cost and benefit changes experienced by all travelers in the network.
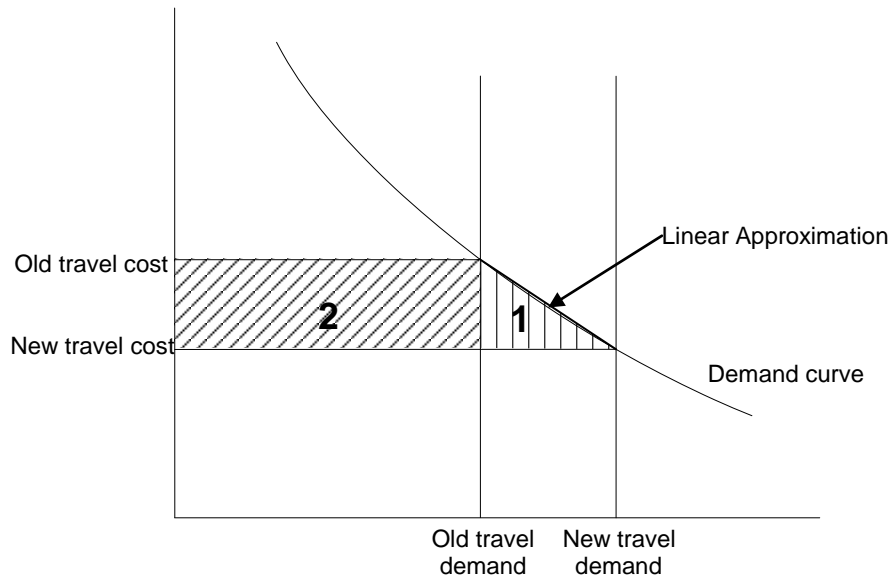
Figure 10.3: Rule-of-Half Showing Changes in Traveler Welfare as Travel Cost Falls

Tolling revenues are estimated based on mode-specific traffic volumes. Tolling revenue is the product of the toll price and the number of vehicles of the corresponding transportation mode on the tolled link, summed across all modes, links, and TOD periods.

10.2 Reliability Evaluation

PET anticipates **uncertainty in travel times**, so that such values may be summed over connecting links, along with travel times for route choices. Such uncertainty is estimated as the convex relationship between freeway volume-capacity ratios and travel time variances using traffic data provided by Cambridge Systematics. The relationship is similar to a shifted version of the BPR function for calculating link travel time, as follows in Equation 10.4:

$$r_a = r_a^0 \left(1 + \sigma \left(\gamma + \frac{v_a}{c_a}\right)^\tau\right)$$ (10.4)

where r_a^0 is the free-flow travel time variance of link a, and σ, γ and τ are function parameters, estimated using traffic data provided by Cambridge Systematics. The data were obtained from 2- to 5-mile-long freeway segments in Atlanta, Los Angeles, Seattle, and Minneapolis (Margiotta, 2009); the resulting estimates (by nonlinear least squares regression) are $\sigma = 2.3$, $\gamma = 0.7$, and $\tau = 8.4$.

PET multiplies travel time unreliability by each user's VOR and sums over all links to determine the total system reliability costs, as recommended by Horowitz (2010). The **default value of VOR** (in terms of hours of standard deviation in travel time) is **assumed to equal** each traveler type's respective **VOTT**. Users should be cautioned that reliability estimates are derived from freeway data, rather than being roadway-type specific. Preliminary case studies by Fagnant et al. (2010) show that monetary reliability benefits can be very high in later years, if networks congest dramatically under certain traffic growth assumptions; such reliability impacts can then dominate all other impacts (including construction costs) for capacity expansion projects. Of course, users may elect to set all traveler values of reliability to $0 in order to omit reliability impacts from B/C ratios and other summary measures.

10.3 Safety Evaluation

Crashes are predicted using **safety performance functions** (SPFs) derived from AASHTO's (2010) *Highway Safety Manual*. These SPFs allow users to pivot off existing crash rates and crash counts to estimate future numbers of fatal or injurious (F+I) and property-damage-only (PDO) crashes on each link in the system. Key factors are link functional classification, AADT, and number of lanes. Local land use type, median type, and intersection control also have important safety impacts along arterials, while entrance and exit ramp frequencies are important for freeways. Segment (link) crashes are estimated for all coded roadway types, and intersection crashes are estimated for arterials and rural roads. All SPFs assume a base set of conditions applicable to the specific facility or intersection type. Any deviations from these base conditions should result in different predicted crash rates. **Crash modification factors** (CMFs) may be applied to individual links in order to obtain more accurate crash predictions.

The analyst may enter CMFs in the *Network Information* sheets in order to change the rate at which crashes are expected to occur on a given link or at a given intersection. These CMFs may be obtained from the *Highway Safety Manual* (AASHTO, 2010). If considering using CMFs, however, the analyst must ensure that these factors are applied consistently in order to obtain rigorous results. If the analyst wishes to increase the accuracy of crash rate estimates across all links and intersections, CMFs should be obtained from the *Highway Safety Manual*. However, the analyst may wish to apply CMFs only to segments where improvements are being made as the estimation of all network CMFs can be time consuming. In this case, CMFs should be obtained only for features that are changing between the base case (no build) and alternative scenario(s).

10.3.1 Motor Vehicle Crash Costs

PET's default is to include the monetary impacts of motor vehicle crashes when assessing each project's **Net Present Value** (NPV), **Benefit Cost** (B/C) ratios, **Internal Rate of Return** (IRR), and **Payback Period** (PP). Default crash costs were obtained from the USDOT guidelines (Trottenberg and Rivkin, 2011), specifically as recommended for TIGER grant analyses (USDOT 2012). These values **include market costs** (in 2011 dollars), such as lost productivity, medical services, travel delay, and property damage, as well as **non-market factors**, such as the statistical value of life, pain and suffering, and values based on "willingness to pay" in order to avoid collisions. Because PET estimates the total number of crashes using the KABCO scale, Table 10.1's conversion values were obtained from the USDOT (Wang, 2010).

Table 10.1: Conversion of MAIS to KABCO Crash Designations with Estimated Market Costs (Wang 2010)

MAIS Value	No Injury (O)	Possible Injury (C)	Non-Incap. Injury (B)	Incap. Injury (A)	Killed (K)	Economic Cost
0	0.92535	0.23431	0.08336	0.03421	0	$3,285
1	0.07257	0.68929	0.76745	0.55195	0	$18,600
2	0.00198	0.06389	0.10884	0.20812	0	$291,400
3	0.00008	0.01071	0.03187	0.14371	0	$651,000
4	0	0.00142	0.00619	0.03968	0	$1,649,200
5	0.00003	0.00013	0.00101	0.01775	0	$3,676,600
Killed	0	0.00025	0.00128	0.00458	1	$6,200,000
Total	1	1	1	1	1	
Economic Cost (2010)	$2,090	$41,240	$80,761	$296,515	$6,200,000	

Other crash valuations may opt to consider only pure market/economic crash costs when using strict crash-to-dollar conversions. As such, pain and suffering and the statistical value of life using other methods may still be incorporated into final analyses, as PET reports anticipated crash changes at each level of severity. PET users who wish to value only **market costs** may refer to National Safety Council (NSC, 2010) estimates, shown in Table 10.2.

Table 10.2: Market-Based Motor Vehicle Crash Cost Estimates (NSC 2010)

	Willingness to Pay
Crash Severity	(per Injured Person)
Death	$1,410,000
Incapacitating Injury	$69,200
Non-Incapacitating Injury	$22,300
Possible Injury	$12,600
Property Damage Only	$8,900 (no injury)

Analysts should note that crash costs in Table 10.2 are **per injured person**, rather than per crash (as required by PET). The Caltrans B/C model assumes an average of 1.15 fatalities per fatal injury crash and an average of 1.49 injuries per injury crash (Caltrans, 2010).

10.3.2 Crash Severity Distributions

PET estimates **crash severity** based on TxDOT motor vehicle crash statistics (TxDOT 2010). The *Highway Safety Manual* (AASHTO 2010) SPFs do not provide crash estimates by severity for all scenarios, so PET relies on TxDOT (2010) crash severity data to estimate the likely distribution of crash severity, pivoting off the fatal crash estimation. For example, in 2010 118,375 urban crashes resulted in injury or fatality and 169,801 urban crashes resulted in property damage only. PET may use SPFs to determine that for a given scenario, 8.2 injurious (including deadly) crashes would on average occur on a given urban link. PET would then extrapolate that 11.8 PDO crashes would occur on this same link, because statewide data suggest that urban areas average 1.434 (reported) PDO crashes for every one crash of higher severity (i.e., 1.434 is the ratio of PDO to fatal and injurious crashes in Texas).

A set of **fixed shares of crash severity outcomes** (proportions of fatal, incapacitating injury, non-incapacitating injury, possible injury, and property damage only) was assumed for all rural crashes and another set of fixed shares of crash severity outcomes for all urban crashes, regardless of functional classification, speed estimates, and other attributes. Users should use caution when investigating link-level crash severity, because crashes on lower-speed roadways tend to be less severe and certain road types can produce more severe crashes. For example, a crash occurring on an undivided, two-lane highway has a higher probability of being a head-on collision (with higher crash severities) than the probability of a head-on collision on an arterial with a divided median. Furthermore, Kockelman et al. (2006) estimated a model that predicted that "a speed limit increase from 55 to 65 mph on the average section would be associated with a 24% increase in the probability of an occupant being fatally injured, once a crash has occurred" (p. 9). For this reason, severity results should be viewed in aggregate rather than at the individual link level.

10.3.3 Crash Estimates along Freeways

AASHTO (2010) provides SPFs for crash types by facility, severity, and number of vehicles involved (multi- or single-vehicle). For freeway crashes, Equation 10.5 is used:

$$N_{spf,fs,fi} = L \times \exp(a + b \times \ln[c \times AADT_{fs}]) \tag{10.5}$$

where $N_{spf,fs,fi}$ is the base number of crashes for freeway segments, L is the freeway segment length, $AADT_{fs}$ is the annual average daily traffic for the length and a, b, and c are SPF coefficients, shown in Table 10.3. Fatal and injury crashes are summed for multi- and single-vehicle crashes, based on individual link parameters (number of lanes and setting [urban vs. rural]).

Table 10.3: Coefficients for Freeway Safety Performance Functions (AASHTO 2010)

Crash Severity	Area Type	Lanes	Multiple-Vehicle Crashes			Single-Vehicle Crashes		
			a	b	c	a	b	c
Fatal and Injury	*Rural*	4	-5.975	1.492	0.001	-2.126	0.646	0.001
		6	-6.092	1.492	0.001	-2.055	0.646	0.001
		8	-6.140	1.492	0.001	-1.985	0.646	0.001
	Urban	4	-5.470	1.492	0.001	-2.126	0.646	0.001
		6	-5.587	1.492	0.001	-2.055	0.646	0.001
		8	-5.635	1.492	0.001	-1.985	0.646	0.001
		10	-5.842	1.492	0.001	-1.915	0.646	0.001

10.3.4 Crash Estimates along Arterials

Many equations are used in PET to anticipate the number of crashes along arterials. These equations are coded into PET's *Link Crashes* and *Intersection Crashes* sheets. Crash rates depend on link-level volumes, lengths, and various parameters, such as number of lanes, presence of medians, and urban or rural setting, as well as intersection configuration (three-leg or four-leg) and presence of stop-sign control. Readers should note that equation number refer to labels from the *Highway Safety Manual* (AASHTO 2010).

The *Highway Safety Manual's* (HSM's) equations 10-6, 11-7, and 11-9 apply to rural arterial segments:

- Rural, two-lane, two-way road segments: HSM Equation 10-6
  $$N_{spf\,rs} = AADT(L)(365)(10^{-6})(e^{-0.312})$$

- Rural, multi-lane, undivided road segments: Equation 11-7
  $$N_{spf\,ru} = \exp[-9.653 + 1.176\ln(AADT) + \ln(L)]$$
- Rural, multi-lane, divided road segments: Equation 11-9
  $$N_{spf\,rd} = \exp[-9.025 + 1.049\ln(AADT) + \ln(L)]$$

Urban arterial segment crashes are predicted by HSM equations 12-10 (for multiple-vehicle collisions) and 12-13 (for single-vehicle crashes). These crashes refer to crashes that are not associated with driveways (i.e., crashes involving vehicles either pulling out of driveways or slowing down to turn into driveways). SPF coefficients vary by number of lanes and separation of directional lanes—by either a two-way left turn lane (TWLTL), a divider such as a median, or may be undivided.

- Multiple-vehicle non-driveway collisions: HSM Equation 12-10
  $$N_{brmv} = \exp[a + b\ln(AADT) + ln(L)]$$
  where values of a and b are as follows for various roadway configurations:

Configuration	a	b
2 Lane Undivided	-15.22	1.68
3 Lane TWLTL	-12.40	1.41
4 Lane Undivided	-11.63	1.33
4 Lane Divided	-12.34	1.36
5 Lane TWLTL	-9.7	1.17

- Single-vehicle crashes: HSM Equation 12-13
  $N_{brsv} = \exp[a + b \ln(AADT) + ln(\text{L})]$
  where values of a and b are as follows for various roadway configurations:

Configuration	a	b
2 Lane Undivided	-5.47	0.56
3 Lane TWLTL	-5.74	0.54
4 Lane Undivided	-7.99	0.81
4 Lane Divided	-5.05	0.47
5 Lane TWLTL	-4.82	0.54

Multi-vehicle driveway crashes are described similarly by HSM equation 12-6, but also vary by land use and facility type (major or minor arterial). Total crashes for urban arterials are determined by summing HSM equations 12-10, 12-13, and 12-16.

- Multiple-vehicle driveway-related collisions: HSM Equation 12-16

$$N_{brdwy} = \sum_{\substack{all\ driveway \\ types}} n_j N_j \left(\frac{AADT}{15000}\right)^{(t)}$$

where n_j is the number of number of driveways of type j shown in the following table and N_j and t are specified as shown in this table:

Configuration	2 Lane Undivided	3 Lane TWLTL	4 Lane Undivided	4 Lane Divided	5 Lane TWLTL
Major Commercial	0.158	0.102	0.182	0.033	0.165
Minor Commercial	0.050	0.032	0.058	0.011	0.053
Major Indusial	0.172	0.110	0.198	0.036	0.181
Minor Industrial	0.023	0.015	0.026	0.005	0.024
Major Residential	0.083	0.053	0.096	0.018	0.087
Minor Residential	0.016	0.010	0.018	0.003	0.016
t	1	1	1.172	1.106	1.172

Pedestrian and bicycle crashes for urban and suburban arterials are also calculated, based on free-flow speed (FFS) and roadway configuration as a function of vehicular crashes calculated from HSM equations 12-10, 12-13, and 12-16. Equations 12-19 and 12-20 are used to determine vehicle-pedestrian and vehicle-bicycle collisions, respectively.

- Vehicle-pedestrian collisions: HSM Equation 12-19

  $N_{pedr} = N_{br} f_{pedr}$

  where

  $N_{br} = N_{brmv} + N_{brsv} + N_{brdwy}$

  as specified above, and f_{pedr} is specified as shown in this table:

Configuration	FFS ≤30 mph	FFS >30 mph
2 Lane Undivided	0.036	0.005
3 Lane TWLTL	0.041	0.013
4 Lane Undivided	0.022	0.009
4 Lane Divided	0.067	0.019
5 Lane TWLTL	0.030	0.023

- Vehicle-bicycle collisions: HSM Equation 12-20

  $N_{pedr} = N_{br} f_{biker}$

  where

  $N_{br} = N_{brmv} + N_{brsv} + N_{brdwy}$

  as specified above, and f_{biker} is specified as shown in this table:

Configuration	FFS ≤30 mph	FFS >30 mph
2 Lane Undivided	0.018	0.004
3 Lane TWLTL	0.027	0.007
4 Lane Undivided	0.011	0.002
4 Lane Divided	0.013	0.005
5 Lane TWLTL	0.050	0.012

10.3.5 Crash Estimates for Intersections

The *Highway Safety Manual* also provides SPFs for estimating intersection crashes under various alignments, environments, and methods of control. For instance, HSM equation 11-11 is applied for rural intersections, based on volume of differences between major and minor cross-streets.

- Rural, multi-lane, intersections: HSM Equation 11-11

  $N_{spf\,rd} = \exp[a + b\ln(AADT_{maj}) + c(AADT_{min})]$

  where values of a, b, and c are as follows for various intersection configurations:

Configuration	a	b	c
3-leg Stop	-12.526	1.204	0.236
3-leg Signal	-7.182	0.722	0.337
4-leg Stop	-10.008	0.848	0.448
4-leg Signal	-7.182	0.722	0.337

The same formula is applied to calculate multiple- and single-vehicle crashes in urban settings (HSM equations 12-21 and 12-24), except with varying SPF coefficient values, shown here.

- Urban and suburban multiple-vehicle crashes: HSM Equation 12-21
  $$N_{bimv} = \exp[a + b \ln(AADT_{maj}) + c \ln(AADT_{min})]$$

Configuration	a	b	c
3-leg Stop	-13.36	1.11	0.41
4-leg Stop	-12.13	1.11	0.26
3-leg Signal	-8.90	0.82	0.25
4-leg Stop	-10.99	1.07	0.23

- Urban and suburban single-vehicle crashes: HSM Equation 12-24
  $$N_{bisv} = \exp[a + b \ln(AADT_{maj}) + c \ln(AADT_{min})]$$

Configuration	a	b	c
4-leg Stop	-6.81	0.16	0.51
4-leg Stop	-9.02	0.42	0.40
3-leg Signal	-5.33	0.33	0.12
4-leg Stop	-10.21	0.68	0.27

Pedestrian and bicycle crashes are calculated for intersections as well, with coefficients varying by configuration.

- Vehicle-pedestrian collisions, signalized *OR* stop-controlled

  Signalized: HSM Equation 12-29
  $$N_{pedbase} = \exp[a + b \ln(AADT_{maj}) + c \ln(AADT_{min})]$$

  Unsignalized: HSM Equation 12-30
  $$N_{pedi} = N_{bi} f_{pedi}$$
       where
       $N_{bi} = N_{bimv} + N_{bisv}$
  as specified above, and f_{pedi} is specified as shown in this table:

Configuration	f_{pedi}
3-leg Stop	0.021
4-leg Stop	0.022

- Vehicle-bicycle collisions: HSM Equation 12-31
  $$N_{bikei} = N_{bi} f_{bikei}$$
       where
       $N_{bi} = N_{bimv} + N_{bisv}$
  as specified above, and f_{bikei} is specified as shown in this table:

Configuration	f_{bikei}
3-leg Stop	0.016
4-leg Stop	0.011
3-leg Signal	0.018
4-leg Stop	0.015

10.3.6 Crash Estimates along Ramps and Collectors

Bonneson and Pratt (2009) estimated the following ramp SPF (Equation 10.6):

$$C_{base} = 0.000365 \cdot base \cdot AADT_{ramp}$$ (10.6)

where C_{base} is the base number of fatal and injury (F+I) crashes and $base$ is the base F+I crash rate per million vehicles. PET assumes a default value of 0.28 crashes per million vehicles for *base,* which is the average of 18 ramp type crash rates provided by Bonneson and Pratt (2009) and the value to be used for diagonal exit ramps with no frontage roads. CMFs for other ramp types may be found in PET's *CMF* sheet. Ramp type definitions may be found in the *Roadway Safety Design Workbook*, Chapter 5 (Bonneson and Pratt, 2009).

Collector crash estimates are based on the average number of traffic crashes per hundred million vehicle miles on two-lane, two-way Texas roads (TxDOT, 2009). A linear relationship is assumed between traffic volume and the number of crashes for all collector crash estimates.

10.4 Environmental Evaluation

PET estimates the environmental impacts of transportation development projects in the form of **vehicle emissions**. While other environmental considerations must often be accounted for (such as impacts to streams, Section 4F lands, and other environmentally sensitive areas), the nature of these impacts leads to a more effective estimate when evaluated outside of PET's framework. Vehicle emission quantities are predicted using lookup tables generated by the EPA's MOVES2010a. The lookup tables are included as a set of workbooks in the *sketch_toolkit.xlsm*. The lookup tables are a set of 2 sheets (*Running Emissions* and *Starting Emissions*), the first 22 columns by 8,064 rows, the second 22 columns by 10,752 rows. Columns represent vehicle types and rows represent combinations of emissions types, pollutant species, climate contexts, modeling years, facility types, and speeds. In total, these sheets provide a total of 413,952 potential lookup values. These lookup tables estimate individual emission outputs in grams per mile for 14 species: 1,3-Butadiene (**BUTA**), Acetaldehyde (**ACET**), Benzene (**BENZ**), Methane (**CH4**), Carbon Monoxide (**CO**), Carbon Dioxide (**CO2**), Formaldehyde (**FORM**), Nitrous Oxide (**N2O**), Ammonia (**NH3**), Nitrogen Dioxide (**NOx**), Particulate Matter < 10 μm (**PM 10**), Particulate Matter < 2.5 μm (**PM 2.5**), Sulfur Dioxide (**SO2**), and Volatile Organic Compounds (**VOC**).

Emissions rates depend on **facility type** (freeway, arterial, local road, or ramp); **vehicle speed** (16 speed categories—from 2.5 mph and slower to 72.5 mph and faster); **climate and seasonal context** (three regions in Texas and two settings for winter or summer); **year of analysis** (based on analysis year closest to 2010, 2015, 2020, or 2025, and impacting vehicle ages [and thus rates]); and **vehicle type** (22 types). PET estimates the number of light and heavy duty vehicles on each link and their respective speeds. Sub-categories of light and heavy vehicles are then extrapolated from overall vehicle fleet distribution tables. Emissions rate estimates are provided for normal exhaust generation of all emissions types and for emissions associated with engine starts.

PET estimates link-level emissions based on the total number of light (8,500 lbs. and under) and heavy vehicles on a link as well as the link's classification and speed estimates. PET estimates speed using the traffic flow result from the travel demand forecasting procedures described earlier. Temperature ranges and analysis year should be provided by the user in the parameter estimates portion of PET. Additional vehicle fleet makeup information is available in the *Vehicle Fleet Information* sheet and may be modified by the analyst as new information becomes available. This information lists the distribution of average vehicle classification within the modeled network. Default values are derived from TxDOT vehicle registrations as compiled by Texas Transportation Institute (2011).

As an example of the lookup table operation, an arterial link may be estimated to carry 1,000 light vehicles and 100 heavy vehicles in a given hour, operating at an average speed of 35 mph. The analysis may be for 2010 with an average summer temperature of 85 degrees. Using the default registration and age data, 16.21% of the light vehicles would be assumed to be 0 to 2 years old, 4.09% would be 3 to 7 years old, etc. The resulting hourly emissions rates would then be used to generate quantities of the 14 emissions on the link. This computation is simultaneously performed for heavy vehicles on the same link and then summed over all links in the system. Daily values are estimated for either a winter or a summer context, as well as annual quantities for each scenario, in the design life year as well as in the initial analysis year. In this way, PET arrives at an average annual emissions tonnage for each species. Users should see Appendix B for more information on the MOVES emissions estimates file structure.

Toolkit defaults do not monetize emissions, though values may be used as recommended by US Transportation Secretary Ray LaHood (2011) based on EPA analysis of the social costs of carbon emissions. These range from $1,700 per metric ton of VOCs, $4,000 per ton of NOx, $16,000 per ton of SO_2, and $168,000 per ton of PM (all 2007 $US), with variable CO_2 costs ranging from $5 to $136 per metric ton, depending on scenario, year, and discount rate used. PET estimates emissions per day for all scenarios across the 14 different species.

PET estimates these levels both in the project's initial year and the design life year, across all scenarios. Daily and annual emissions quantities are reported, as well as changes in emissions between the base case (no build) and alternative scenarios. PET also estimates the increase (or decrease) in emissions quantities for the base case over the project design life due to traffic growth and fleet turnover.

10.5 Fuel Use Estimation

PET estimates individual traveler **fuel consumption as a function of vehicle speeds** (West, 1997) **and average fleet fuel economy**. Average fleet fuel economy estimates between 2010 and 2050 were obtained from Kite (2009) using MOBILE 6.2 defaults. West's data set relied on fuel economy values for a single test vehicle averaging 26.8 mpg. PET applies a fleet fuel economy factor (total estimated fuel consumption divided by VMT) to account for the diverse range of individual vehicle fuel economies. Total fuel use is the sum of estimated fuel rate consumed on each link. Total fuel use also depends on the amount of miles traveled by electric vehicles (EVs), which can be changed by the user. Fuel use in PET considers only gasoline or diesel fuel and does not consider various upstream fuels used to produce electricity for EVs. PET's EV calculations do, however, consider the emissions replacements from power sources and use data

based on the Texas power grid network represented by the Electric Reliability Council of Texas (ERCOT); see Section 2.7.6 for details.

10.6 Operational Strategy Evaluation

The Main Toolkit File and associated travel demand model programs are designed for evaluating transportation network improvements through a static travel demand modeling approach on the sketch planning level. It models a transportation network in the node-link form, where a node represents an intersection and a link represents a section of roadway between two intersections. The node-link representation ignores some network components, control devices, and information systems on the operational level and may not be able to properly capture the modeling details and traffic effects caused by these operational strategies.

This document provides methodology for implementing operational strategies including **speed harmonization**, **shoulder lane use**, **ramp metering**, **signalization**, **managed lanes**, **incident management,** and **advanced traveler information systems** (ATIS). Shoulder lane use and ramp metering may be modeled by changing existing link capacity in one or more of the alternative scenarios. Managed lanes may be directly implemented in PET by adjusting tolling rates by vehicle class and time of day, as well as varying capacity by time of day, if desired. Signalization strategies may be modeled by changing the network configuration to model one or more signalized intersections. Impacts from these strategies may be estimated without use of PET's travel demand model, and the process for conducting these evaluations is described in Section 3.6.

The following text provides a set of guidelines and recommendations, based on the previous knowledge from the literature, on how PET could be directly or indirectly used to evaluate or approximate a list of operational strategies for the transportation planning purpose.

10.6.1 Shoulder Lane Use

PET estimates shoulder lane use impacts by **increasing capacity** for times of day when travelers are allowed to use the shoulder as a travel lane. Previous experiences justified using shoulder lanes as an effective capacity bottleneck relief strategy during traffic peak hours or under emergency conditions to accommodate extra traffic. This operational strategy is often used simultaneously with speed harmonization, though one strategy may be employed without the other. Benefits have been reported from implementing shoulder lane use, including a travel time reduction of up to 20% and a temporary increase of up to 25% in freeway capacity (FHWA, 2010).

When implementing shoulder lane use, three case studies in particular are informative as to the potential capacity increases that may be realized, as shown in Table 10.4. Note that original dimensions reported in the studies have been converted from metric to English units, rounding to the nearest half foot.

Table 10.4: Observed Capacity Increases with Shoulder Lane Use

Source	Strategy	Location	Capacity increase
Riegelhuth, G. and A. Pilz. (2007)	Shoulder use during peak periods. Lane configuration was three 11.5' lanes and a 10' shoulder in each direction.	Hessen, Germany	Section capacity was increased by 1,150 vph in each direction.
Cohen(2004)	Reduction of existing lane widths, increasing should width and allowing shoulder lane travel during peak periods. Four 11.5' lanes and a 6.5' shoulder in each direction were converted into a 10' lane, and four 10.5' lanes, with a remaining width allocated for curb access.	Paris, France	Section capacity increased by 660 vph in one direction and 1,070 vph in the other. The capacity of the existing lanes showed some reduction, though less than the capacity increase from the new lane.
Middleham (2003)	Use of shoulder lanes during peak periods. Existing road sections were two 11.5' lanes in each direction, divided motorway with 10.5' shoulder.	Netherlands	Up to 50% of existing capacity (the shoulder added capacity similar to what would be expected from adding a conventional lane).

Temporary shoulder use may also be used in combination with speed harmonization to increase the throughput rate of congested highways, as shown in the example in Figure 10.4. In this example, the addition of the third lane in the form of temporary shoulder use, while slightly decreasing speed and initially reducing volumes on the highway, delays the onset of congestion and breakdown and increases the overall throughput on the facility. Similar operational improvements are realized as a result of speed harmonization, with breakdown flow under breakdown conditions being reduced, as shown in Figure 10.4.
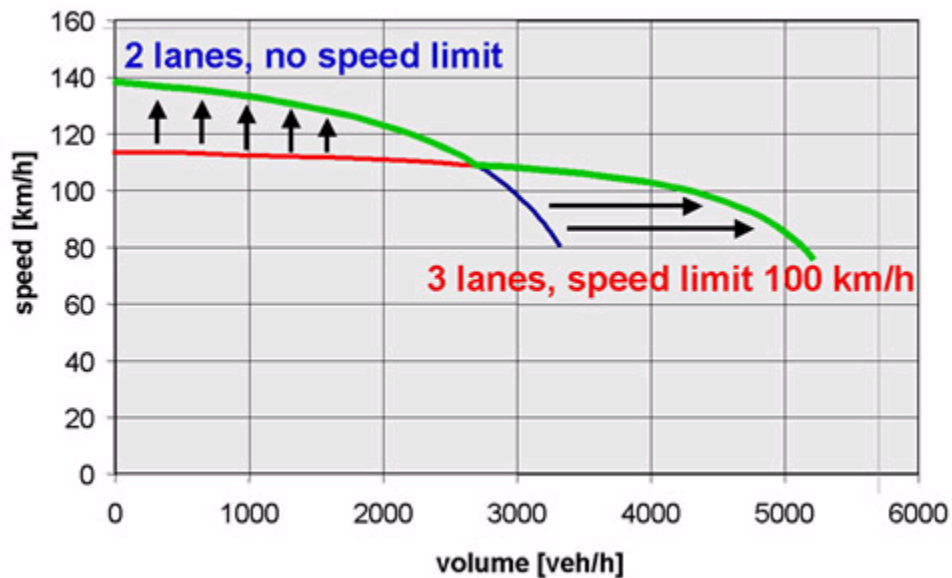
Figure 10.4: Example Speed-Flow Relationship Change from Using a Temporary Shoulder Lane (FHWA 2010)

10.6.2 Speed Harmonization

PET estimates predicted benefits from Speed Harmonization in the form of **crash reductions**. To properly quantify the traffic and safety impacts of speed harmonization, the Operational Toolkit File estimates the number of crashes expected to occur during the peak period when speed harmonization would be active, then applies a recommended 10–30% crash reduction factor to those crashes, depending on the figure determined by the analyst. The analyst may also choose to investigate both the high and low range to get a better understanding of the likely range of potential impacts.

Reference information and case studies in different regions and under different traffic congestion conditions can be found in the FHWA's highway capacity summary report (FHWA, 2010). The report also provides estimates of safety benefits from implementing shoulder lanes and speed harmonization. A list of the case studies and their impacts on transportation supplies and demands retrieved from the report are presented in Table 10.5.

Table 10.5: Example Case Studies of Speed Harmonization

Case Study Location	Quantitative Impact(s)
Netherlands, Case Study I (Van Toorenburg, 1983)	• An increase in capacity of 1–2% was reported.
Netherlands, Case Study II (Van den Hoogen and Smulders, 1994)	• Reported no effect on the capacity/throughput. • Observed more uniform traffic. • Suggested that variable speed limit leads to improved safety.
UK (Borrough, 1997)	• 28% less crashes.
UK, Motorway M25 (Harbord, 1998)	• More even headways. • 28% reduction injury accidents. • 25% reduction in damage only accidents. • It was not possible to show that journey times had improved with any reasonable level of statistical significance.
Finland (Rama, 1999)	• Reducing the speed limit from 100 km/h to 80 km/h decreased the speed by only 5.3 km/h in free-flow traffic conditions.
UK, Motorway M25 (UK Highway Agency, 2004)	• 10% reduction in injury accidents. • The ratio of damage-only accidents to injury accident dropped by 20%. • Overall emissions reduced by 2–8% (Nissan, 2010).
Germany (FHWA, 2000)	• Variable speed limit has been reported to lead to a 20–30% reduction in the crash rate.
Snoqualmie Pass, WA (Ulfarsson et al., 2005)	• Reported an average reduction in the mean speed of 6 km/h.
Austin, TX (Wang and Walton, 2006)	• By reducing the speed limit from 65 mph to 55 mph on "Ozone Action days," the average daily total NOx emission in a 24-hour period was reduced by approximately 17 % on the selected IH-35 segment.

Two findings/recommendations are suggested by synthesizing these results. First, speed harmonization is particularly **beneficial for transportation safety** (due to more uniform speeds and headways), as measured by the number of accidents. Moreover, while different control strategies have been employed in these various real-world implementations, the reduction in

crash rates typically ranges from 10% to 30%. Second, speed harmonization typically **does not change capacity**/throughput of a roadway to any substantial degree. For example, Van den Hoogen and Smulders (1994) concluded that the traffic throughput rate showed no apparent change, whereas Waller et al. (2009) reported increases in capacity of around 1% at most.

10.6.3 Ramp Metering

Ramp metering is a freeway traffic control system by which traffic entering the freeway's mainline through a ramp is "metered" to ensure the level of service on the mainline on an acceptable level. It is implemented using a ramp signal that ensures short delays occur at on-ramps and freeway-to-freeway intersections, regulating the merging flow and minimizing merge-related disruptions. Ramp metering plays an important role in improving freeway traffic conditions by breaking up platoons of vehicles (to minimize merging-related disruptions), regulating flows that enter the freeway (to avoid exceeding capacity at downstream bottlenecks), diverting local traffic to less-congested arterials, and providing priority for buses and high-occupancy vehicles (HOVs) (Colman, 1997). Typical metering is rated ranging from 240 to 1,100 vehicles per hour per lane, with lower metering rates resulting in higher violation rates and longer ramp queues, but better freeway performance.

While a number of pre-timed and actuated metering control mechanisms are used in practice, the direct result of using a ramp metering system is to control the traffic passage time on the ramp—in effect reducing the ramp's capacity. To properly accommodate the traffic impact of a ramp meter, the user needs to **identify the effective capacity** of the ramp controlled by a metering device. When the entering flow rate on the ramp is relatively high, the link capacity reduction is approximately proportional to the reduction of the allowable traffic passage time; when the entering flow on the ramp is very light, the effective link capacity reduction may be ignored. To accurately quantify the capacity reduction effects, a microscopic simulation study under a variety of geometric and traffic conditions is preferable. If simulation is not feasible, ramp capacity may be estimated as a fraction of non-metered ramp capacity multiplied by the percentage of available green time in a given cycle.

10.6.4 Signal Control

While PET **cannot explicitly model the signal control at intersections** and take into account signal delays into the travel demand forecasting module, PET can **incorporate** the **traffic delays estimated externally** into the travel demand forecasting and other evaluation and analysis processes. A signal may be approximated by developing an intersection from a single node, as shown in Figure 10.5. This converts a four-leg intersection with signal control from a node to an intersection subnetwork of 8 nodes and 12 links in PET. (In the case of three-leg junctions, the corresponding intersection subnetwork consists of six nodes and six links.)
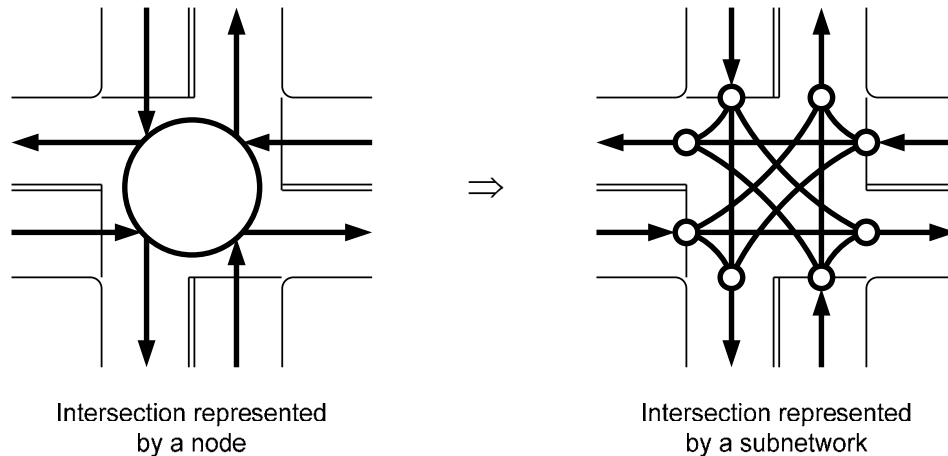
Figure 10.5: Using Links to Explicitly Represent Turning Movements at Intersections

Added intersection links specify left-turn, right-turn, and through traffic movements. The analyst must then estimate initial traffic volumes on each intersection, which in turn may be used to externally estimate turning movement delays for each alternative scenario. As each intersection link is assumed to use the same link performance function as all other non-intersection links, analysts should set free-flow speed such that free-flow travel times are equal to expected delay with expected volumes, and to set capacity values high. This will properly incorporate a signal into the network-based traffic assignment and other travel choice processes in PET's travel demand model.

Analysts may use commercial software such as Synchro or HCS, or manually perform calculations using the Highway Capacity Manual (AASHTO 2010) to estimate signal delays for various turning movements. Alternatively, protected turning movements may be quickly estimated using Webster's function (Webster 1958), shown in Equation 10.7:

$$d = \frac{C[1-g/C]^2}{2[1-v/s]} + \frac{(v/c)^2}{2v[1-v/c]} - 0.65(c/v^2)^{1/3}(v/c)^{2+g/C} \qquad (10.7)$$

where C is the cycle length, g is the green time, v is the traffic demand rate, s is the saturation flow rate, and c is the capacity of lanes corresponding to the turning movement. Other models for calculating signal delays can be found in a widely cited review paper (Hurdle 1984).

For permitted turning movements (e.g., permitted left-turn movements and right-turn movements), due to the extra delay imposed by opposing flows, estimating the signal delays is much more complex. Moreover, in this situation, the signal delays are the functions of opposing flow rates, which can be no longer regarded as a purely external parameter. Some empirical analytical models or simulation models are needed to approximate the signal delays for a variety of traffic conditions before the delays values are fed into PET.

10.6.5 Managed Lanes

Managed lanes are typically defined as a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions. The principal management

strategies can be categorized into three groups: **pricing**, **vehicle eligibility**, and **access control**. Examples of operating managed lane projects include reversible lanes, HOV lanes, high-occupancy toll (HOT) lanes, or exclusive or special use lanes, such as transit or taxi priority lanes. Each of these concepts offers unique benefits; careful consideration needs to be given to project goals and objectives in choosing an appropriate lane management strategy or combination of strategies. A set of example managed lane applications in traffic network management is categorized in Figure 10.6.
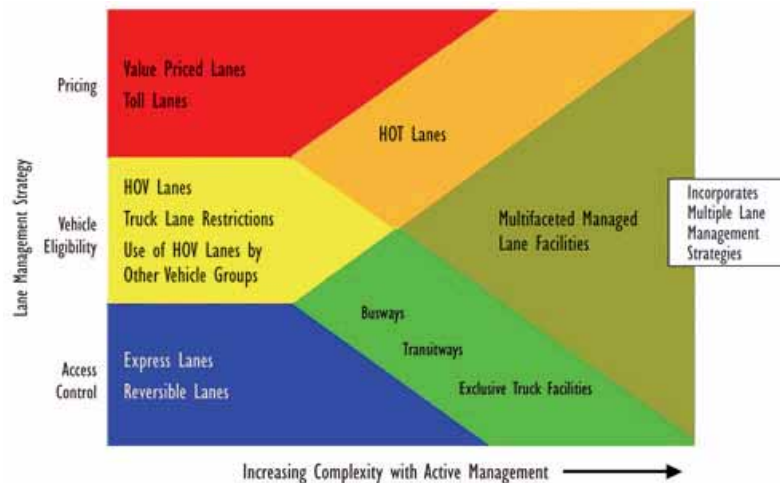
Figure 10.6: Example Managed Lane Applications (FHWA 2005)

PET can accommodate most of these functions, with **variable pricing by time of day and mode**, and **variable capacity settings by time of day** available for each traffic link. This facilitates the quick and easy use of various pricing schemes, HOT lanes, and reversible lanes. The most significant limitation is in modeling vehicle eligibility. In order to perform this task, the user must set toll prices very high for all ineligible vehicles (for example, $1,000 for all non-transit vehicles on a bus only lane), then ignore all tolling revenues obtained on these links if one or two ineligible vehicles use the link anyways. While this work-around is imperfect, analysts can still obtain useful scenario outcomes within a reasonable margin of error.

To model **reversible lanes**, the user can exchange capacity and numbers of lane between reverse traffic directions of a roadway between different TOD periods. To allow **HOV** or **HOT** lanes, the user should model these lanes as separate, parallel links to the original links and accordingly reduce the capacity of the original links, as well as reset the tolls for those exclusive transportation modes, i.e., non-HOV or non-HOT vehicles, to be extremely high. Users must also allow for an on- or off-link between the main lanes and the HOV or HOT lane(s) to avoid PET's parallel link limitations. HOV and HOT settings can also vary over times of day.

10.6.6 Incident Management

An incident is a non-recurring event that causes a reduction of roadway capacity such as traffic crashes, disabled vehicles, spilled cargo, or brush fire. PET estimates incident management impacts as a combination of **travel time savings** and changes in **emissions** due to changes in

travel speeds. Incident management is implemented by estimating the number of crashes that occur during peak periods on links that have been targeted with incident management strategies. From these figures, total numbers of **lane-blocking incidents during peak periods** is then estimated. PET then uses measures of before and after incident clearance times to estimate total upstream delay, using Wirasinghe's (1978) estimation of delay as shown in Equation 10.8:

$$d = \frac{1}{2}t^2 \frac{(q_a - q_l)(q_c - q_l)}{(q_c - q_a)} \tag{10.8}$$

where d is the total delay caused by the incident (hours), t is the incident duration (hours), q_a is the arriving flow rate (vph), q_l is the leaving flow rate past the incident (vph), and q_c is the capacity of the roadway facility. Note that no delay is estimated on the facility if the lane closure results in a capacity that still exceeds the arrival flow rate.

While various incident management strategies have been used in the real world, evaluating the effectiveness and benefits of these strategies is a challenging task. Table 10.6 summarizes the benefits from a list of recent incident management cases. These numbers can be used as references to approximate the possible range of benefits if an incident management strategy is applied to the network evaluated by PET.

Table 10.6: Benefits of Example Incident Management Cases

Source	Strategy	Location	Incident Duration Reduction	Primary Accident Reduction	Secondary Accident Reduction	Travel Time Reduction	Traffic Delay Reduction	Fuel Consumption Reduction	Benefit/Cost Ratio	Used Equipment
Helman (2004)	Towing and clearance service	Seattle, WA	75%							Car with special tools
Helman (2004)	Monitoring of police resources, towing and clearance service	Fairfax County, VA	40%							Monitor
ITS America (2010)	DTI, ATIS, variable congestion-pricing system	Miami, FL	45%		45%					Monitor, camera, detector
Kaan Ozbay (2005)	Freeway service patrol	Los Angeles, CA							15:1	
Kaan Ozbay (2005)	Freeway service patrol	Houston, TX							6.6:1 to 23:1	
ITS America (2009)	Patrol program and NaviGA	Atlanta, GA							4:1	
ITS America (2009)	DTI and traffic signal alteration	San Antonio, TX			2.8%		5.7%	1.2%		
ITS Benefits and Unit Costs Database (2002)	Video cameras, lane control signs, dynamic message signs, comm. network	San Antonio, TX		35%	30%					CCTV, loop detector
Johnson and Thomas (2000)	Traffic monitoring, incident response, traveler information	Baltimore, MA	57% in 2000 55% in 1999				15.6 M vehicle hours, 1997	5.85 M gallons, 1997	7:1	
Shah and Wunderlich (2001)	Pre-trip traveler information systems (ATIS), highway advisory radio (HAR), ramp metering, VMS	Detroit, Michigan				4.6 min average	22%			

10.6.7 Advanced Traveler Information Systems

Similar to incident management, PET does not evaluate total network impacts from an ATIS implementation project. Potential ATIS benefits are approximated by estimating non-recurring traffic congestion caused by incidents and alerting/guiding travelers to **alternative routes**. Benefits are then assessed in the form of monetized **travel time savings**.

PET enables user to simultaneously implement and evaluate three different ATIS strategies. Default strategies include highway advisory radio (HAR), variable message signs (VMS), and a third ATIS strategy with parameters that may be set by the user. Travel time savings are estimated by predicting the number of incidents based on expected crashes, determining the number of persons who benefit from ATIS strategies by changing their route and saving time, and calculating the average travel time savings and dollar value of those persons who are helped by ATIS. Equations 10.9–10.12 serve as the basis of ATIS benefits:

$$VOTTS = (VOTT)(AVO)(TSTTS) \tag{10.9}$$

$$TSTTS = \sum_{l=1}^{L} IMV_l (ATTS_l) \tag{10.10}$$

$$IMV_l = AADT_l (INC_l)(AvgINCD_l)(pctHPkTrf)(pctTRVINF_l)(pctCHGRTE_l) \tag{10.11}$$

$$INC_l = CRASH_l (MajINCpC) \tag{10.12}$$

The variables and parameters are defined in Table 10.7.

Table 10.7: Variable and Parameter Sources for ATIS Strategies

Abbreviation	Definition	Comments
VOTTS	Value of Travel Time Savings ($)	Estimated using Equation 10.9
VOTT	Average Value of Travel Time	Obtained from Summary Input Information
AVO	Average Vehicle Occupancy	Obtained from Summary Input Information
TSTTS	Total System Travel Time Savings	Estimated using Equation 10.10
IMVl	Number of Impacted Vehicles by implementation of ATIS strategy on link l	Estimated using Equation 10.11
ATTSl	Average Travel Time Savings of impacted vehicles on link l	See below
AADTl	Average Annual Daily Traffic Volume on link l	Obtained from Main Toolkit File
INCl	Number of annual Incidents on link l	Estimated using Equation 10.12
AvgINCDl	Average Incident Duration on link l	Base case duration obtained from Summary Input Information. See below for alternative case incident duration.
pctHPkTrf	Hourly peak hour traffic as a percentage of AADT	Obtained from Summary Input Information
pctTRVINFl	Percentage of travelers Informed by the ATIS strategy on link l	See below
pctCHGRTEl	Percentage of travelers who are informed of the incident by the ATIS strategy and Change their Route as a result on link l	See below
CRASHl	Average annual predicted or historical number of crashes on link l	Obtained from Main Toolkit File
MajINCpC	Major Incidents per Crash. Major incidents include those blocking one or more lanes and include incidents of all sources, not just crashes (i.e., breakdowns, cargo spills, etc.).	Obtained from Summary Input Information

As noted in Table 10.8, key parameter values include

- The percentage of travelers who are informed by the ATIS strategy on each link,

- The percentage of the travelers who are informed that alter their route and save time, and

- The average travel time savings of those who change their route.

A default value may be entered that will be applied to all links, though the analyst may opt to assign link-specific values for these three measures, and average incident duration. Suggested values for these three component measures were obtained from the IDAS manual (2003), shown in Table 10.8 as a list of ATIS cases implemented in different network contexts.

Table 10.8: Benefits of Example ATIS Cases

ATIS Deployment	Impact Estimation Parameters	Default Value	Impact Estimation - Travel Time and Throughput	Benefits Estimation
Highway Advisory Radio	Percent vehicles that tune to broadcast	5%	[Person-hours saved]=∑[traffic person-volume]*[HAR usage percentage]*[percent time that extreme conditions are occurring]*[HAR usefulness percentage]*[average amount of time savings in hours]	[△In-vehicle travel time monetary benefit]=[Person-hours saved]*3*[Normal In-vehicle value of time]
	Percent vehicles hearing broadcast that save time	25%		
	Percent time that extreme traffic conditions are occurring	10%		
	Average amount of time saved by each traveler saving time under extreme traffic conditions	4min		
Freeway Dynamic Message Sign	Percent time sign is turned on and is disseminating information that can be used to save travel time	10%	[Person-hours saved]=∑[traffic person-volume]*[percent time sign is turned on]*[percent vehicles passing sign that save time]*[average amount of time savings in hours]	[△In-vehicle travel time monetary benefit]=[Person-hours saved]*3*[Normal In-vehicle value of time]
	Percent vehicles passing sign that save time	28%		
	Average amount of time saved by each traveler saving time	11min		
Transit Dynamic Message Sign	Number of DMS	#	[Travel time savings]=∑[number of trips originating at zone]*[percent travelers looking at information as they depart]*[percent travelers that may be able to save time]*[average amount of time saved]	[△User Mobility monetary benefit]=[Travel Time Savings]*3*[Normal value for travel time reliability]
	Percent travelers looking at information	50%		
	Of those travelers looking at information, percentage that will then be able to save time	20%		
	Average amount of time saved by each traveler saving time	2min		

ATIS Deployment	Impact Estimation Parameters	Default Value	Impact Estimation - Travel Time and Throughput	Benefits Estimation
Telephone-Based ATIS	Market penetration (the percentage of travelers calling the system as they depart)	0.50%	[Travel time savings]=∑[O-D trips]*[market penetration]*[in-coverage delay time]*[maximum delay savings]	[∆In-vehicle travel time monetary benefit]=[Travel Time Savings]*3*[Normal In-vehicle value of time]
	Maximum amount of time saved by each traveler	15% of in-coverage delay time for up to 10% market penetration, 0% of in-coverage delay time for 60% market penetration		
Web/Internet-Based ATIS	Market penetration (the percentage of travelers using the Internet for travel information as they depart)	0.5% in 2000, 5% in 2005, 10% in 2010, 20% in 2015, 30% in 2020, straight line extrapolation for 2020 and beyond	[Travel time savings]=∑[O-D trips]*[market penetration]*[in-coverage delay time]*[maximum delay savings]	[∆In-vehicle travel time monetary benefit]=[Travel Time Savings]*3*[Normal In-vehicle value of time]
	Maximum amount of time saved by each traveler	20% of in-coverage delay time for up to 10% market penetration, 10% of in-coverage time for 40% market penetration, 0% of in-coverage delay time for 60% market penetration		
Kiosks with Transit-Only Traveler Information	Number of kiosks	#	[Travel time savings]=∑[number of trips originating at zone]*[percent travelers looking at information as they depart]*[percent travelers that may be able to save time]*[average amount of time saved]	[∆User Mobility monetary benefit]=[Travel Time Savings]*3*[Normal value for travel time reliability]
	Percent travelers looking at information	5%		
	Percentage of people looking at information may be able to save time	20%		
	Average amount of time saved by each traveler saving time	2min		

ATIS Deployment	Impact Estimation Parameters	Default Value	Impact Estimation - Travel Time and Throughput	Benefits Estimation
Kiosks with Multimodal Traveler Information	Number of kiosks	#	[Travel time savings]=∑[number of trips originating at zone]*[percent travelers looking at information as they depart]*[percent travelers that may be able to save time]*[average amount of time saved]	[△User Mobility monetary benefit]=[Travel Time Savings]*3*[Normal value for travel time reliability]
	Percent travelers looking at information	0.05%		
	Percentage of people looking at information may be able to save time	40%		
	Average amount of time saved by each traveler saving time	3min		
Handheld/In-Vehicle Devices with Traveler Information	Total number of handheld or in-vehicle devices	#	[Travel time savings]=∑[O-D trips]*[market penetration]*[activation factor]*[in-coverage delay time]*[maximum delay savings]	[△In-vehicle travel time monetary benefit]=[Travel Time Savings]*3*[Normal In-vehicle value of time]
	Market penetration (the percentage of travelers using handheld and in-vehicle traveler information systems for basic travel information [no route guidance])	0.5% in 2000, 5% in 2005, 10% in 2010, 20% in 2015, 30% in 2020, straight line extrapolation for 2020 and beyond		
	Percentage of travelers that have system activated during trip	50%		
	Maximum amount of time saved by each traveler saving time	20% of in-coverage delay time for up to 10% market penetration, 10% of in-coverage time for 40% market penetration, 0% of in-coverage delay time for 60% market penetration		

ATIS Deployment	Impact Estimation Parameters	Default Value	Impact Estimation - Travel Time and Throughput	Benefits Estimation
Handheld/In-Vehicle Devices with Route Guidance	Total number of handheld or in-vehicle devices	#	[Travel time savings]=∑[O-D trips]*[market penetration]*[activation factor]*[in-coverage delay time]*[maximum delay savings]	[ΔIn-vehicle travel time monetary benefit]=[Travel Time Savings]*3*[Normal In-vehicle value of time]
	Market penetration (the percentage of travelers using handheld and in-vehicle traveler information systems for basic travel information and route guidance)	0.5% in 2000, 5% in 2005, 10% in 2010, 20% in 2015, 30% in 2020, straight line extrapolation for 2020 and beyond		
	Percentage of travelers have the system activated during a trip	50%		
	Maximum amount of time saved by each traveler saving time	25% of in-coverage delay time for up to 10% market penetration, 12.5% of in-coverage time for 40% market penetration, 0% of in-coverage delay time for 60% market penetration		

10.7 Summary Measure Estimation

Evaluating and comparing transportation projects are typically based on a variety of performance metrics typical of engineering economic analyses. PET uses four such metrics: NPV, B/C ratios, IRR, and PP. PET uses project cost and monetized scenario impacts (such as traveler welfare, reliability, crashes [default, economic components only], and emissions [default, not included]) to estimate these measures. (Note: fuel costs are not directly included because they are already represented in traveler welfare valuations. Also, tolling revenues are not included in these analyses and must be analyzed separately.)

PET produces summary measures for each project scenario, over the project lifetime. All measures require a base-case (typically no-build) point of reference to determine project impacts in terms of changes in traveler welfare and other benefits having monetary equivalents. The discount rate and the project design life may be specified by the user.

Traveler welfare (emphasizing travel time and vehicle operating costs) is **always included** in these summary measures. Travel time reliability, motor vehicle crash costs, and air pollutant costs may be monetized and included in the summary economic measures at the discretion of the analyst. By **default**, PET monetizes market or **economic components of crash costs only** (including property damage, medical costs and lost productivity). The default does **not monetize emissions costs**, simply because these vary with exposure to population and remain rather uncertain and undocumented by the EPA. However, the Guide's Appendix C provides ranges of potential valuations users can input if they elect to monetize these. **Fuel consumption is not included** in the summary measures because the operating costs component already accounts for traveler welfare valuations.

The following equations illustrate how the program calculates all performance metrics. Note that even if one scenario alternative has a B/C ratio or NPV superior to a competing scenario alternative, it does not automatically mean that the first should be automatically pursued. Other considerations must be taken into account, including non-monetized impacts, available agency funding, and means of financing projects, through measures such as tolling revenues.

NPV is the project's worth over the entire design life (e.g., 20 or 30 years, up to a maximum of 75 years) in present dollars (measured from the initial build year). NPV is calculated as shown in Equation 10.13:

$$NPV = -C_i + SV\left(\frac{1}{1+DR}\right)^{PL} - IPC\left(\frac{1}{1+DR}\right)^{YR} + \sum_{y=1}^{PL}\left(B_y - C_y\right)\left(\frac{1}{1+DR}\right)^{y} \qquad (10.13)$$

where C_i is the initial project cost, SV is the salvage value, IPC is the interim project costs, DR is the discount rate (as a proportion, rather than as a percentage), B_y denotes the benefits realized in year y, and C_y denotes costs realized in year y. Typical project lifetimes (PL) are likely to be 20 years in application of the tool kit. (Note: only one PL value may be given, in order to better compare all projects on an equal footing.)

The **B/C ratio** is the sum of discounted (initial-year) benefits (relative to the base case/no-build scenario) divided by the sum of discounted project costs, as shown in Equation 10.14:

$$B/C \ Ratio = \frac{\sum_{y=1}^{PL}(B_y)(\frac{1}{1+DR})^y}{C_i + \sum_{y=1}^{PL}(C_y)(\frac{1}{1+DR})^y - SV(\frac{1}{1+DR})^{PL} + IPC(\frac{1}{1+DR})^{YR}} \tag{10.14}$$

where variables are defined as above. All project impacts are assumed to be benefits and all changes to agency budgets are assumed to be costs. Thus, benefits include changes in traveler welfare (operating cost and travel time) as well as crash costs and emissions (if monetized), while costs include only hard dollar costs to the transportation agency. This evaluation may include both negative benefits (for example, if crash costs increase) and negative costs (for example, if maintenance costs are reduced). Again, tolling revenues are not included in B/C ratios (because they are both a benefit to the collecting agency and a cost to the travelers) and must be evaluated independently. Otherwise, project costs could approach zero or become negative if revenues exceed projected costs, rendering the B/C ratio analysis virtually meaningless.

The **PP** is the point at which the sum of the non-discounted annual benefits first equals the sum of all project costs, relative to the base case scenario. This is calculated using Excel's embedded financial calculator to solve the following equation (Equation 10.15):

$$C_i = \sum_{y=1}^{PP}(B_y - C_y) \tag{10.15}$$

If the sum of the benefits over the project life never exceed the project costs (initial and annual), PET will report that the scenario's payback period is greater than the project design life.

The project's **IRR** determines the discount rate at which the sum of discounted costs equals the sum of discounted benefits (at their present-year worth). This is calculated using Excel's embedded financial calculator to solve Equation 10.16:

$$IRR = C_i + \sum_{y=1}^{PL}(C_y)(\frac{1}{1+IRR})^y - SV(\frac{1}{1+IRR})^{PL} + IPC(\frac{1}{1+DR})^{YR} = \sum_{y=1}^{PL}(B_y)(\frac{1}{1+IRR})^y \tag{10.16}$$

If the benefit-cost ratio is negative (i.e., disbenefits exceed benefits), PET will report that the scenario's IRR is not applicable (N/A).

Chapter 11. Sensitivity Analysis

PET's sensitivity analysis procedure is conducted using the **Monte Carlo simulation** technique. The statistical distribution of potential results is approximated by running PET's computation process a pre-specified number of times, each of which represents a random sample. PET allows any combination of parameters to vary, with the user specifying a coefficient of variation for each (defined as the standard deviation divided by the mean). Up to 100 sensitivity testing trials may be run at a time. For each sensitivity testing trial, a random draw is taken from a **lognormal distribution** for each parameter that is set to vary. This variation will be held constant across all like values, across scenarios, and for the initial and design years (for example, all Values of Travel Time may decrease by 3% for a given trial). This file is then saved in the text file "VariationFile.txt" to allow analysts to go back and compare results to parameter variations.

If the network is set to vary, individual network files will be created for each sensitivity testing trial. If parameters in the parameter variation file are set to vary, parameter files will be created for each sensitivity testing trial. If the trip growth rate is set to vary, design year growth files will be created for each sensitivity testing trial. Note that the variation of some parameters will not impact any input files used in the travel demand modeling process and are used only when assessing final impacts for a given trial run (for example, initial project costs). Table 11.1 lists all parameter that are allowed to vary (which may be set in the *Summary Input Information* sheet—see Section 2.4) and the travel demand model input files that are impacted as each parameter varies.

Table 11.1: Sensitivity Testing Parameters

Parameter	Impacts
Value of Time	Parameter Files
Vehicle Operating Costs	Parameter Files
Value of Reliability	Parameter Files and Post TDM Results
Value of Crashes	Post TDM Results
Value of Emissions	Post TDM Results
Link Capacity	Network Files and Post TDM Results
Capacity Parameters (Alpha & Beta, Link Performance Func.)	Network Files and Post TDM Results
Free-flow Speed	Network Files and Post TDM Results
Reliability Parameters (sigma, tau, Reliability Est. Equation)	Post TDM Results
Crash Rate	Post TDM Results
Emissions Rate	Post TDM Results
Mode Scale Parameter	Parameter Files
TOD Scale Parameter	Parameter Files
Temperature	Post TDM Results
Average Vehicle Occupancy	Parameter Files
Base User Class Proportions	Parameter Files
Base Mode Split %'s	Parameter Files
Trip Growth Rate	DY Growth Files
Demand Elasticity	Parameter Files
Initial Project Costs	Post TDM Results
Additional Maint. & Op. Costs	Post TDM Results

Analysts should note that if the Base User Class Proportions are set to vary, a random draw will be conducted for each user class, and similarly for each mode if Base Mode Split %'s are set to vary. Thus, for example, User Type 1 may draw a 20% increase, User Type 2 a 12% decrease, and User Type 3 a 4% increase. After adjusting the base shares by their respective decreases or increases, all shares would be normalized such that the total proportion of all User Types (or mode split percentages) still sums to 1.0.

Upon creation of the sensitivity testing files used in the travel demand model, a single base trip table will be estimated. Then, the travel demand modeling process will be conducted using the specified number of iterations for each scenario's initial year and design year. Once this is complete, PET's Main Toolkit File loads the travel demand model's outputs, loads parameter variations used to assess the post travel demand model results, and records the resultant key outputs. This process continues until all sensitivity testing results have been completed.

Chapter 12. Budget Allocation

12.1   Budget Allocation Methodology

PET is designed as an alternative analysis tool that may be used to identify desirable project scenario alternatives. The final component for use after conducting initial project investigations is the budget allocation module. This component may be used to perform an optimal project selection function by **identifying a preferred mix of potential projects** in order to achieve the maximum benefits. This component solves a discrete optimization problem (i.e., maximization of total benefits caused by project implementation) subject to certain constraints—for example, budget limits and equity considerations ensuring that various regions have minimum expenditure levels. Moreover, the budget allocation module requires the analyst to specify a pre-determined level of required investment for every candidate project, under the assumption that one project's costs will not impact another project's cost. In this regard, the budget allocation decision-making process will choose mix of projects that will deliver the maximum benefits, within the limits of budget and other constraints.

The standard budget allocation problem is the classic 0-1 "**knapsack problem**" (Martello and Toth, 1990). Given a set of candidate projects, each of which is associated with a fixed cost (e.g., design and construction cost) for its implementation and known monetized benefits (e.g., increases in consumer surplus and travel time reliability), and given a total-budget constraint (to cover selected project costs), the objective is to find an optimal subset of projects to be implemented so that total benefits (or net benefits) are maximized without violating/exceeding the budget constraint.

This problem and other more complex discrete optimization problems can be solved by utilizing Excel's Solver add-in or Microsoft Solver Foundation. PET includes a budget allocation module example problem that uses the Excel's Solver add-in that demonstrates how analysts can develop budget allocation scenarios when determining which projects to fund. Figure 12.1 illustrates the setup used in the example problem, with one input column for project costs, one for project benefits setting, and a third the Solver add-in uses to report which projects should be selected in order to achieve the maximum benefit, subject to budget and other constraints. The user simply specifies all the input data (e.g., project costs and net present values) and parameters (e.g., budget and emissions constraints) in one or more Excel spreadsheets. The optimal set of project choices (as well as iteration information derived by the Solver add-in) can be placed in cell locations specified by the user. The current version of this add-in can accommodate up to a maximum of 200 decision candidate projects. For more information about Microsoft Excel's Solver add-in, interested readers may refer to http://office.microsoft.com/en-us/excel-help/load-the-solver-add-in-HP010021570.aspx.

For problems with more than 200 project options, consider the Microsoft Solver Foundation (MSF). This commercial optimization software package (with a freely downloadable express edition) can solve a variety of large-scale linear, nonlinear, integer, and stochastic optimization problems. MSF allows use of any CLI (Common Language Infrastructure) language (e.g., VB, C#, J#) to customize their models. Though MSF is not part of Microsoft Excel, it shows up as an

Excel add-in (after its installation) and uses Excel sheets to store and manipulate its input and output data. For more information about MSF's functionalities and capabilities, interested readers can refer to http://www.solverfoundation.com/.

12.2 Using the Budget Allocation Module in PET

To use the Budget Allocation Module, specify potential project names, anticipated project costs, anticipated project benefits, region, and project type for all candidate projects. Anticipated project costs and benefits may be obtained by using PET's main toolkit component (as discussed previously in other sections of the Users' Guide) or from other sources, if desired. Next specify all constraints, including a total budget constraint, as well as minimum and maximum funding levels for each region and each project type. Once this is completed, click on the "Data" menu bar in Excel and select "Solver" to open the Solver window. Next click "Solve" and the Budget Allocation Module will inform the analyst which projects are recommended for funding, the total cost of the selected projects, and the total anticipated benefits. Figures 12.1 and 12.2 show the Budget Allocation Module's required inputs, outputs, and user interface for a set of example candidate projects.

								Total cost	$659,703

Note: If "Recommended Projects for Funding" value between 0 and 1, press "options" in the Solver window and un-check "Ignore Integer Constraints"

						Total benefit	$1,685,028

Legend

User Inputs	
Key Outputs	

	Project	Name	Cost	Benefit	Region	Project Type		Recommended Projects for Funding (1/0)
	1	Aus Hwy	$138,506	$282,191	1	1		1
	2	Aus Trans	$95,905	$102,530	1	2		0
	3	Aus PdBike	$141,893	$88,243	1	3		0
	4	DFW ITS	$85,190	$162,184	2	4		1
	5	DFW Maint	$116,260	$62,828	2	5		0
	6	DFW Hwy	$105,494	$181,549	2	1		0
	7	Hou Trans	$8,737	$22,055	3	2		1
	8	Hou PdBike	$144,007	$143,497	3	3		1
	9	Hou ITS	$104,161	$127,270	3	4		0
	10	SA Maint	$48,320	$197,392	4	5		1
	11	SA Hwy	$36,840	$274,041	4	1		1
	12	SA Trans	$72,290	$166,783	4	2		1
	13	Tyler PdBike	$26,177	$104,964	5	3		1
	14	Tyler ITS	$76,726	$109,491	5	4		1
	15	Tyler Maint	$22,910	$222,430	5	5		1

Figure 12.1: Budget Allocation Module User Inputs for Example Candidate Projects

Constraints					
	Budget	$700,000			
				Max Funding	Min Funding
$ of Projects in Region 1		$138,506		$200,000	$50,000
$ of Projects in Region 2		$85,190		$200,000	$50,000
$ of Projects in Region 3		$152,743		$200,000	$50,000
$ of Projects in Region 4		$157,450		$200,000	$50,000
$ of Projects in Region 5		$125,813		$200,000	$50,000
				Max Funding	Min Funding
$ of Projects of Type 1		$175,347		$200,000	$50,000
$ of Projects of Type 2		$81,027		$200,000	$50,000
$ of Projects of Type 3		$170,184		$200,000	$50,000
$ of Projects of Type 4		$161,916		$200,000	$50,000
$ of Projects of Type 5		$71,230		$200,000	$50,000

Figure 12.2: Budget Allocation Module Constraints for Example Candidate Projects

Chapter 13. Multi-Objective Decision-Making

13.1 Multi-Objective Decision-Making Methodology

PET's multi-objective decision-making tool (MODMT) enables engineers, planners, and other users to select one or more optimal projects or scenarios from among competing alternatives, subject to multiple criteria that are not all monetized or reduced to a single type of unit (e.g., not all are resolved in minutes saved or dollars saved). The MODMT uses data envelopment analysis (DEA), a methodology that uses an "efficiency" value to rank different scenarios (Charnes et al. 1978, Seiford and Thrall 1990). Scenarios whose efficiency is less than one are clearly dominated by other scenarios, and are not recommended; the scenarios with an efficiency greater than or equal to one are potentially optimal candidates, depending on the relative valuation of the different criteria. The magnitude of the efficiency value reflects the degree to which these scenarios are dominated (or not) by the others. This method is not sensitive to the units used for each criterion, and has an intuitive geometric interpretation (Figure **Error! Reference source not found.**), making it a useful choice for the toolkit.

DEA operates by first identifying an "efficient frontier" of outcomes that maximize benefits while minimizing costs. Any outcome for which a superior outcome can be expressed as a linear combination of two other outcomes is deemed inefficient. For example, if three projects have respective initial costs (cost), crash savings (benefit), and travel time savings (benefit) of (2,4,4), (2,2,8), and (2,3,5), the third project may be said to be inefficient since 7/12*(4,4) + 4/12*(2,8) = (3,5). This means that a linear combination of the first two projects could realize the same benefit as the third project at 11/12 of the third project's cost.

Once inefficient projects have been eliminated, DEA operates by identifying super-efficiency measures. The super-efficiency value quantifies the degree to which a project expands the efficient frontier of outcomes. If this value is less than one, a project is inefficient, and the same benefits can be achieved with lower cost using the other alternatives. If the value is exactly equal to one, the project is efficient, but does not extend the range of possibilities provided by the other projects. Even if this project was not one of the chosen alternatives, the same benefits could be achieved with identical cost based on the remaining alternatives. A super-efficiency value greater than one indicates that including this project as an alternative *expands* the efficient frontier, and provides a new combination of benefits that could not be achieved by other projects in the set. The magnitude of the super-efficiency indicates the extent of this expansion. Projects that are found to have the best super-efficiency scores are likely to be the best candidates when pursuing optimal decisions across a wide array of metrics without direct conversion between competing criteria.

The super-efficiency value for a project (say, project X) is calculated by first identifying feasible combinations of the other alternatives being considered. A feasible combination is one that at least matches all of the benefits of project X; the super-efficiency value for *that particular combination* is the ratio of the cost of that combination to the cost of project X (and if there are multiple cost metrics, the highest ratio among all of the costs). The super-efficiency value for a project is the lowest super-efficiency value for each feasible combination. That is, the super-

efficiency value is based on the ratio of costs between the least-cost combination of other alternatives that can reproduce project X's benefits, and project X itself.
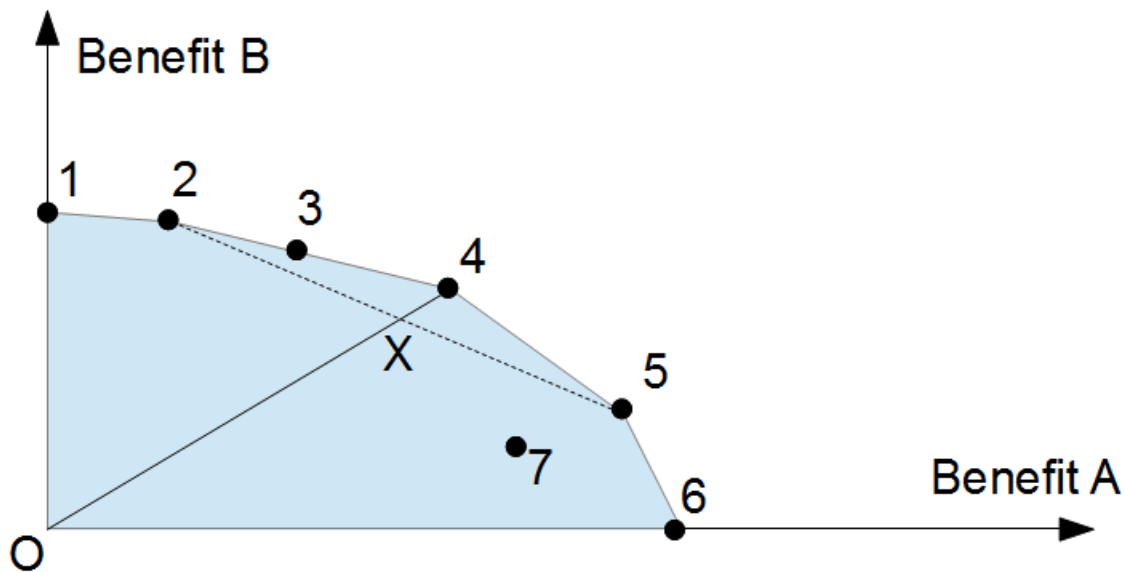
Figure 13.1: Example showing intuition behind super-efficiency calculations. Project 7 has a super-efficiency score less than one because it is inefficient. Project 3 has a super-efficiency score equal to one: the project is on the efficient frontier, but removing this project from consideration would have no effect on the frontier. Project 4 has a super-efficiency score greater than one: its removal would shrink the efficient frontier to the dotted line. The score can be thought of as the ratio between the distances O-4 and O-X.

The MODMT serves a similar purpose as the Budget Allocation Module, with the ability to select multiple alternatives from among competing choices. However, whereas the existing Budget Allocation Module uses a single objective function (maximizing total monetized benefits of chosen projects), the MODMT evaluates competing alternatives across multiple benefits (or costs) that do not necessarily have "fixed" tradeoffs. Having both components enables analysts to choose the method that best suits their particular situation.

13.2 Using the Multi-Objective Decision-Making Tool in PET

DEA has been implemented as an Excel spreadsheet, in which the user specifies each of the scenarios, and the values of each of the corresponding measures of effectiveness. Further, the user specifies whether each of these metrics is either a "benefit" (a higher value is better, such as with traveler welfare or revenue) or a "cost" (a lower value is better, as with emissions, crash rates, or construction and maintenance costs). MODMT outputs sort scenarios by their efficiency values, giving analysts effective project prioritization rankings.

To use the MODMT, simply specify the name of each candidate project and any combination of up to 10 total benefit and cost metrics. Next, note the score for each metric across all candidate projects. Analysts should note that units across metrics do not need to be consistent. For example, the first metric may be mobility benefits in hours of travel time savings, the second metric could be annual number of anticipated crashes averted, and a third metric could be

construction costs. Once all metrics have been specified, click the "Rank projects" button. The MODMT will then use the DEA methodology as described above in order to assign efficiencies to each project. The project with the greatest efficiency should be the project with the greatest overall benefits and lowest overall costs, while the project with the lowest efficiency should be the least desirable project. Figure 13.2 shows an example project input using the MODMT; Figure 13.3 shows the resulting outputs and ordering of recommended projects.

Project	Name	Metric 1 Benefit	Metric 2 Benefit	Metric 3 Benefit	Metric 4 Cost	Metric 5 Cost	Metric 6 Unused
1	Bike Trail	500	10	150	500	40	
2	Sidewalks	450	10	200	700	50	
3	Corridor Reconstr 1	1500	0	0	1000	150	
4	Corridor Reconstr 2	1700	-10	100	1200	200	
5	Roundabout	1200	40	300	600	50	
6	Traffic Signal	1000	7	-200	500	100	
7							

Figure 13.2: MODMT User Inputs for Example Candidate Projects

Project	Name	Efficiency	Metric 1	Metric 2	Metric 3	Metric 4	Metric 5
5	Int. Roundabout	3.333333	1200	40	300	600	50
6	Int. Signal	1	1000	7	-200	500	100
3	Corridor Reconstr 1	0.75	1500	0	0	1000	150
4	Corridor Reconstr 2	0.708333	1700	-10	100	1200	200
2	Sidewalks	0.666667	450	10	200	700	50
1	Bike Trail	0.625	500	10	150	500	40

Figure 13.3: MODMT Super-efficiency Rankings Example Candidate Projects

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Appendix A: Implementing Specific Project Types

This guide provides users with detailed descriptions on how to use and understand PET. This section provides guidance to users on implementing a number of various project types. This section assumes that the user has already verified all parameter values and only needs to develop the alternative scenario. Note that more than one project or project type may be implemented within a single alternative scenario.

A.1   Capacity Addition and Functional Classification Upgrades

Step 1: Navigate to the appropriate *Alternative Scenario Link Configuration* sheet (Figure A.1).

Step 2: Modify the *Link Capacity* of impacted links.

Step 3: Modify the *Functional Classification* of impacted links, if changing.

Step 4: Modify the *Number of Lanes* on the impacted links, if changing.

Step 5: Modify the *Free-flow Speed* if free-flow speed is different than the default.

Step 6: If intersections are being removed, added, or changed (such as due to grade separation), navigate to the appropriate alternative arterial and rural highway intersection sheet, and make changes as required.

Step 7: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 8: Run the travel demand model and review results.

Link Characteristics									Freeway Only (Optional)				Arterial Only		Capacity Per Lin
Length (mi)	Link Class	Area Type	FF Speed (User Entered)	FF Speed	FF Time	#Lanes	CMF	AADT	Variable Capacity (0/1)	#Entr Ramps (User Entered)	#Exit Ramps (User Entered)	#Entr Ramps	#Ex Ramps	Land Use	Median	Link Capacity (pc/hr)
1	1	1		55	1.1	3		16500	0	1	1	1	1			5730
1	1	1		55	1.1	3		16500	0	1	1	1	1			5730
7.8	1	1		55	8.5	3		75000	0	7	5	7	5			5730
7.8	1	1		55	8.5	3		75000	0	7	8	7	8			5730

Figure A.1: Key Inputs for Capacity Addition and Functional Classification Upgrades

A.2   Roadway Pricing

Step 1: Navigate to the appropriate *Alternative Scenario Tolling* sheet (Figure A.2).

Step 2: Modify the *Toll Settings* of impacted links for times of day and modes, as desired.

Step 3: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 4: Run the travel demand model and review results.

AM Toll Settings					Mid Day Toll Settings					PM Toll Settings				
Vehicle Class 1	Vehicle Class 2	Vehicle Class 3	Vehicle Class 4	Vehicle Class 5	Vehicle Class 1	Vehicle Class 2	Vehicle Class 3	Vehicle Class 4	Vehicle Class 5	Vehicle Class 1	Vehicle Class 2	Vehicle Class 3	Vehicle Class 4	Vehicle Class 5
$2.00	$2.00	$2.00		$5.00	$2.00	$2.00	$2.00		$5.00	$2.00	$2.00	$2.00		$5.00
$2.00	$2.00	$2.00		$5.00	$2.00	$2.00	$2.00		$5.00	$2.00	$2.00	$2.00		$5.00

Figure A.2: Key Inputs for Roadway Pricing

A.3   Reversible Lanes

Step 1: Navigate to the appropriate *Alternative Scenario Link Configuration* sheet (Figure A.3).

Step 2: Set the *Variable Capacity (0/1)* to 1 for links with reversible lanes.

Step 3: For times of day when the reversible lanes are open in the given link direction, set the *Managed Lanes Capacity* to the full capacity value.

Step 4: For times of day when the reversible lanes are closed in the given link direction, set the *Managed Lanes Capacity* to "1." See note below the figure.

Step 5: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 6: Run the travel demand model and review results.

Variable Capacity (0/1)	Freeway Only (Optional)				Arterial Only		Capacity & Link Performance Parameters			Managed Lanes with Variable Capacity				
	#Entr Ramps (User Entered)	#Exit Ramps (User Entered)	#Entr Ramps	#Ex Ramps	Land Use	Median	Link Capacity (pc/hr)	BPR Formula Alpha	BPR Formula Beta	AM Peak Capacity	Mid Day Capactiy	PM Peak Capacity	Evening Capacity	Off Peak Capacity
1	1	1	1	1			5730	0.83	5.5	5730	5730	1	1	1
1	1	1	1	1			5730	0.83	5.5	5730	5730	1	1	1
1	7	5	7	5			5730	0.83	5.5	1	1	5730	5730	1
1	7	8	7	8			5730	0.83	5.5	1	1	5730	5730	1
0	2	2	2	2			5730	0.83	5.5					
0	2	2	2	2			5730	0.83	5.5					

Figure A.3: Key Inputs for Reversible Lanes

Note: Step 4 assumes that the reversible lanes are separated from the main lanes. If a single reversible lane is used in conjunction with two through lanes, the analyst may model a capacity greater than one. For example, a given link may have a capacity of 6,000 vph when the link has three lanes available to travelers and a capacity of 2,000 vph when the reversible lane changes direction and only two lanes are available.

A.4   Shoulder Lane Use

Step 1: Navigate to the appropriate *Alternative Scenario Link Configuration* sheet (Figure A.4).

Step 2: Set the *Variable Capacity (0/1)* to 1 for links with shoulder lane use.

Step 3: For times of day when the shoulder lane is in use, set the *Managed Lanes Capacity* to the full capacity value with the shoulders being used as active lanes.

Step 4: For times of day when the shoulder lane is closed, set the *Managed Lanes Capacity* to their normal value without the use of shoulder lanes.

Step 5: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 6: Run the travel demand model and review results.

Variable Capacity (0/1)	Freeway Only (Optional)				Arterial Only		Capacity & Link Performance Parameters			Managed Lanes with Variable Capacity				
	#Entr Ramps (User Entered)	#Exit Ramps (User Entered)	#Entr Ramps	#Ex Ramps	Land Use	Median	Link Capacity (pc/hr)	BPR Formula Alpha	BPR Formula Beta	AM Peak Capacity	Mid Day Capactiy	PM Peak Capacity	Evening Capacity	Off Peak Capacity
1	1	1	1	1			5730	0.83	5.5	5730	5730	7000	5730	5730
1	1	1	1	1			5730	0.83	5.5	5730	5730	7000	5730	5730
1	7	5	7	5			5730	0.83	5.5	5730	5730	7000	5730	5730
1	7	8	7	8			5730	0.83	5.5	5730	5730	7000	5730	5730
0	2	2	2	2			5730	0.83	5.5					
0	2	2	2	2			5730	0.83	5.5					

Figure A.4: Key Inputs for Shoulder Lane Use

Note: see Section 8.6.1 for more details on guidance for capacity addition due to shoulder lane use.

A.5   Traffic Safety Projects

Step 1: Navigate to the appropriate *Alternative Scenario Link Configuration* sheet if a traffic link's safety is being improved; use the appropriate *Alternative Scenario Arterial and Rural Highway Intersection* sheet if an intersection is being improved.

Step 2: Set the *Crash Modification Factor (CMF)* as appropriate to change the expected crash rate (Figure A.5).

Step 3: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 4: Run the travel demand model and review results.

FF Speed	FF Time	# Lanes	CMF	Variable Capacity (0/1)
55	1.1	3	0.9	0
55	1.1	3	0.9	0
55	8.5	3		0
55	8.5	3		0

Area Type	Control	CMF
1	SIG	0.75
1	SIG	0.75
1	SIG	
1	SIG	

Figure A.5: Key Inputs for Safety Projects – Link CMF (Left) and Intersection CMF (Right)

Note: see Section 8.3 for more information on sources for CMF values.

A.6   Ramp Metering

Step 1: Navigate to the appropriate *Alternative Scenario Link Configuration* sheet (Figure A.6).

Step 2: Modify the *Capacity* of the impacted ramp or ramps to model the maximum number of vehicles allowed per hour.

Step 3: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 4: Run the travel demand model and review results.

Arterial Only		Capacity & Link Performance Parameters		
Land Use	Median	Link Capacity (pc/hr)	BPR Formula Alpha	BPR Formula Beta
		1800	0.33	3.9
		1800	0.33	3.9
		5730	0.83	5.5
		5730	0.83	5.5

Figure A.6: Key Inputs for Ramp Metering

Note: PET models ramp metering by limiting ramp capacity. However, users should be warned that PET allows traffic volumes to exceed capacity and results should be examined closely, particularly if the results indicate volumes substantially exceeding capacity.

A.7   Speed Limit Changes

Step 1: Navigate to the appropriate *Alternative Scenario Link Configuration* sheet (Figure A.7).

Step 2: Modify the *Free-flow Speed* of the impacted links as desired.

Step 3: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 4: Run the travel demand model and review results.

**Link Characteristics**

Length (mi)	Link Class	Area Type	FF Speed (User Entered)	FF Speed	FF Time	#Lanes
1	6	1		40	1.5	3
1	6	1		40	1.5	3
7.8	1	1	65	65	7.2	3
7.8	1	1	65	65	7.2	3
2.9	1	1		55	3.2	3
2.9	1	1		55	3.2	3

Figure A.7: Key Inputs for Speed Limit Changes

Note: Speed limit changes may also have other impacts that are not modeled by PET. For example, crash severity has been found to increase as speeds rise—as noted by Kockelman et al. (2006)—and PET does not directly account for this effect.

A.8   Advance Traveler Information Systems (ATIS)

Step 1: Navigate to the *ATIS Operational Strategy* sheet (Figure A.8).

Step 2: Estimate the *% of Travelers Informed of Incidents* by the ATIS strategy in the initial and design years.

Step 3: Estimate the *% of Informed Travelers* who change their routes in the initial and design years.

Step 4: Estimate the average travel time savings for travelers changing their route in the initial and design years.

Step 5: Enter the impacted link numbers for which the ATIS strategy will be available.

Step 6: Enter any link-specific non-default values as desired.

Step 7: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 8: Review results. (This analysis type does not require running the travel demand model.)

10		Initial Year	Design Year
11		2011	2021
12	Incidents per Year on Impacted Links	583	629
13	Total # Vehicles on Impacted Links (AADT)	941,000	989,000
14	% of Crashes during Congested Times	61%	61%
15	Lane Blocking Incidents per Crash	2.07	2.07
16	Average Incident Duration (hours)	1.08	1.08
17	% of Travelers Informed of Incident by ATIS	5%	5%
18	% of Informed Travelers Changing Route	25%	25%
19	Average Travel Time Savings for Travelers Changing Route, Congested (min) <ATSC>	4	4
20	# Vehicles Impacted per Year (Congested)	15660	17669
21	Annual Travel Time Savings (hours)	1044	1178
22	Annual Travel Time Monetary Benefits ($)	$20,045	$22,616

Figure A.8: Key Inputs for Advance Traveler Information Systems

Note: suggested values for various ATIS strategy inputs may be found in Section 8.6.7.

A.9   Speed Harmonization

Step 1: Navigate to the *Speed Harmonization* sheet (Figure A.9).

Step 2: Enter the impacted link numbers on which speed harmonization will be used.

Step 3: Enter any link-specific expected percentage of crashes that occur when speed harmonization is active, as desired.

Step 4: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 5: Review results. (This analysis does not require running the travel demand model.)

Impacted Link #'s	Functional Classification	Max Initial Year V/C Ratio, for all Times of Day	#PDO Crashes	#Poss Inj Crashes	#Minor Inj Crashes	#Incap. Injury Crashes	#Fatal Crashes	Alt % Crashes when Active	% Crashes when Active	Alt % Crashes when Active	% Crashes when Active
35	1	0.86	19	8	4	0	0.14		61%		61%
36	1	0.86	19	8	4	0	0.14		61%		61%
37	1	0.87	13	6	3	0	0.10		61%		61%

Figure A.9: Key Inputs for Speed Harmonization

A.10 Incident Management

Step 1: In the Operational Toolkit File, navigate to the *Incident Management* sheet (Figure A.10).

Step 2: Estimate the average lane blocking incident duration with incident management in the initial and design years.

Step 3: Enter the impacted link numbers to which the incident management strategy will be applied.

Step 4: Enter any link-specific non-default values as desired (incident duration with and without incident management, arrival rate as a percentage of AADT, delay savings per incident, for the initial and design years, and percentage of heavy vehicles on each link).

Step 5: Navigate to the *Engineer's Estimate* sheet and update values to reflect scenario costs.

Step 6: Review results. (This analysis does not require running the travel demand model).

	Initial Year	Design Year
	2011	2021
Incidents per Year on Impacted Links	348	179
Total # Vehicles on Impacted Links (AADT)	740,000	777,747
% of Incidents during Congested Times	61%	61%
Lane Blocking Incidents per Crash	2.07	2.07
Average Incident Duration (hours)	1.08	1.08
Average Incident Duration with Incident Management (hours)	0.833	0.833
Arrival Rate per Hour as % of AADT	6.50%	6.50%
Average % Truck Traffic	10%	10%
Annual Travel Time Savings (hours)	173,377	920,431
Annual Travel Time Monetary Benefits ($)	$3,328,832	$17,672,281
Warnings	None	None

Figure A.10: Key Inputs for Incident Management

A.11 Signalization

Step 1: Navigate to the appropriate *Base Scenario Link Configuration* sheet.

Step 2: Add intersection links and nodes to model the intersection's possible turning movements, as noted in Section 8.6.4.

Step 3: Estimate the Base Case Scenario initial year traffic volumes and corresponding delay for each turning movement. Set capacity very high and set free-flow speed such that intersection link free-flow time will equal the expected turning movement delay.

Step 4: Copy the new intersection links to the appropriate *Alternative Scenario Link Configuration* sheet.

Step 5: Estimate the expected volumes in the alternative scenario and corresponding delay for each turning movement. Set free-flow speed such that intersection link free-flow time will equal the expected turning movement delay.

Step 6: Navigate to the *Base Case Arterial and Rural Highway Intersection* sheet and add the signalized intersection.

Step 7: Navigate to the appropriate *Alternative Scenario Arterial and Rural Highway Intersection* sheet and add the signalized intersection.

Step 8: Run the travel demand model for the initial year only.

Step 9: Verify that traffic volumes for each intersection link are such that the resulting travel delays are close to what was estimated for both the base case and alternative scenario before running the travel demand model.

Step 10: Adjust intersection link free-flow speeds as required to hit the target delays based on estimated traffic volumes for the base case and/or alternative scenario, if required. If intersection links need further free-flow speed calibration, re-run the travel demand model for the initial year. Repeat steps 9 and 10 until the estimated link delays from the post-travel demand model results are close to delays specified by the analyst, as per the analyst's engineering judgment.

Step 11: In the *Base Case Scenario Highway Link Configuration* sheet, estimate travel delays for the design year for each intersection link and adjust free-flow speeds such that intersection link free-flow time will equal the expected turning movement delay.

Step 12: In the appropriate *Alternative Scenario Highway Link Configuration* sheet, estimate travel delays for the design year for each intersection link and adjust free-flow speeds such that intersection link free-flow time will equal the expected turning movement delay.

Step 13: Run the travel demand model for the design year only.

Step 14: Verify that traffic volumes for each intersection link are such that the resulting travel delays are close to what was estimated for both the base case and alternative scenario before running the travel demand model.

Step 15: Adjust intersection link free-flow speeds as required to hit the target delays based on estimated traffic volumes for the base case and/or alternative scenario, if required. If intersection links need further free-flow speed calibration, re-run the travel demand model for the initial year. Repeat steps 14 and 15 until estimated link delays from post-travel demand model results are close to delays specified by the analyst, as per the analyst's engineering judgment. When satisfied, review PET output results for each alternative scenario.

Note: Using link free-flow speed to model turning movement delay will produce a single delay value for all times of day. Analysts may opt to also adjust capacity by time of day for the intersection links in order to model more severe delays at certain periods over the course of the day. This, of course, will take additional time for delay estimation, PET computation, calibration, and verification.

Appendix B: Parameter Defaults, Input Descriptions, and Required Inputs for New Projects

Appendix B presents tables containing PET parameter value and user input defaults, sources, and definitions, as well as a series of tables noting the user inputs and parameters required, recommended for evaluation, and useful for more detailed analyses.

B.1   Highway Link Configuration Information

Table B.1 notes key inputs and other PET values used in the *Highway Link Configuration* sheets. Table B.1 also notes whether each value is input by the user or automatically estimated by PET.

Table B.1: Highway Link Information*

Category Name	Info Entered By	Comments
Link #	PET	
From Node #	User	PET assumes all links are directional.
To Node #	User	PET assumes all links are directional.
Link Name	User	Optional, but recommended. Sample format: "Main St: 1st to 2nd."
Length (mi)	User	
Link Class	User	1=freeway, 2=principal arterial, 3=major arterial, 4=minor arterial, 5=collector, 6=ramp
Area Type	User	1=urban, 2=suburban, 3=rural
FF Speed (User Entered)	User	Optional. Link's free-flow (FF) speed (in miles per hour).
FF Speed (Default)	PET	If user enters a value in the link FF Speed (User Entered), that value will be used. Otherwise, a default free-flow speed value will be assigned, based on the link class and area type.
FF Time	PET	Measured in minutes. Based on values in Use FF Speed and Length.
# Lanes	User	Number of through lanes.
CMF	User	Optional. Crash Modification Factor (CMF) based on *Roadway Safety Design Workbook* or other calculations.
AADT	User	Average Annual Daily Traffic (AADT) (in vehs/day) in the initial project year. Required for the Base Highway Link Configuration only. If an analysis is conducted for a project with an expected initial year three years from the most recent traffic counts, the analyst should adjust traffic volumes to reflect expected initial year traffic volumes.
Variable Capacity	User	1 if capacity varies by time of day (i.e., reversible lanes); 0 if capacity remains constant.
# Entr Ramps (User Entered)	User	Optional. Freeway only. Number of entrance ramps on that link.
# Exit Ramps (User Entered)	User	Optional. Freeway only. Number of exit ramps on that link.
# Entr Ramps (Default)	PET	Freeway only. Left blank if the link is not a freeway. If the link is a freeway and a value is entered in the # Entr Ramps input cell, this value will be used. Otherwise the number of entrance ramps will be based on the default average number of entrance ramps per mile link parameter.

Category Name	Info Entered By	Comments
# Ex Ramps (Default)	PET	Freeway only. Left blank if the link is not a freeway. If the link is a freeway and a value is entered in the # Exit Ramps input cell, this value will be used. Otherwise the number of exit ramps will be based on the average number of entrance ramps per mile link parameter.
Land Use	User	Arterials only (non-freeway and non-ramp facilities). 0=rural/residential, 1=industrial, 2=commercial, 3=office.
Median	User	Arterial only (non-freeway and non-ramp facilities). 0=none, 1=two-way left turn lane, 2=restrictive median.
Link Capacity	User	Link Capacity: passenger cars per hour.
Parameter Alpha	PET	Parameter input for speed estimation using Bureau of Public Roads (BPR) link performance function.
Parameter Beta	PET	Parameter input for speed estimation using BPR link performance function.
AM Peak Capacity	User	Road capacity during the AM peak period. Applicable only if the link's variable capacity is set to 1. Similar notes apply to variable capacity by time of day for Midday, PM Peak, Evening, and Off Peak capacities.
TOD Reference	User	References traffic flow TOD distribution station number.
Reference Name	PET	References name of TOD distribution station.
Traffic Vol	PET	Preliminary assessment of vehicles per hour (vph) for each TOD. Automatically calculated by PET based on AADT and TOD references. The travel demand model uses this information to generate trip tables for future year and alternative scenario traffic patterns.
Speed	PET	For each TOD. Estimated from BPR link performance function and V/C ratios.
Travel Time	PET	For each TOD. Multiple of tool-estimated link speed and segment length.
V/C Ratio	PET	For each TOD. Traffic volume divided by link capacity.

*Note: all Toolkit-entered values are simply defaults (or modeling results) that can be modified by users directly, as needed.

B.2 Arterial and Rural Highway Intersection Information

Table B.2 notes key inputs and other PET values used in the *Arterial and Rural Highway Intersection* sheets.

Table B.2: Arterial Intersection Information

Category Name	Comments
Int #	Automatically entered by PET (but modifiable by users).
Node/Intersection Name	Optional but recommended form: Main & 1st St.
Area Type	1=urban, 2=suburban, 3=rural.
Control (SIG/UNSIG)	1=signalized intersection, 2=unsignalized intersection.
CMF	Optional. CMF should be based on the *Roadway Safety Design Workbook* or other relevant document.
Link 1 (Major)	Optional. The corresponding link in the highway link configuration sheet.
Use Link 1 AADT	Optional. Traffic volume of link 1.
Link 2 (Major)	Optional. The corresponding link in the highway link configuration sheet.
Use Link 2 AADT	Optional. Traffic volume of link 2.
Link 3 (Minor)	Optional. The corresponding link in the highway link configuration sheet.
Use Link 3 AADT	Optional. Traffic volume of link 3.
Link 4 (Minor)	Optional. The corresponding link in the highway link configuration sheet.
Use Link 4 AADT	Optional. Traffic volume of link 4.

B.3   Summary Input Information

Tables B.3 through B.7 note information regarding the various parameter subsections of the *Summary Input Information* sheets.

Table B.3: Summary Input Information—General Project Information

Input Name	Comments
# of Alternative Scenarios	
Scenario Names	
Annual Traffic Growth Rate	In percentage points. (Default is 1%.)
Linear or Exponential Traffic Growth	Input '0' if linear and '1' if exponential growth is expected. Exponential growth is the default.
Total Traffic Growth over Project Life	Automatically calculated based on growth rate and linear or exponential growth.
Initial Year	The year in which the project will be fully operational. Note: this is also the default year for input AADT values. If traffic volumes are expected to grow from the input values to the initial year, the analyst should input alternate growth rates for the initial year in the *Travel Growth Rates* sheet.
Discount Rate	PET suggests a 5% real discount rate default. This is lower than the 7% required by the OMB for federal projects, but is on the high end of the 3 to 5% discount rates typically used for state transportation projects, as reported by the FHWA (2007).
Project Design Life	Expected project life before replacement is necessary.

Table B.4: Summary Input Information—Capacity and Reliability Parameters

Input Name	Comments
Default Link Speeds (FF)	Free-flow speeds based on roadway classification and area (urban, suburban, or rural). Obtained from Cambridge Systematics (2008).
Reliability Parameters	Equation and Default Parameters. See Section 8.2, regarding Reliability Estimates, for more information.
Link Performance Function Parameters (α & β)	For use in the HCM 2000's BPR link-performance function. See Section 2.3 for more information. Defaults are $\alpha = 0.83$ and $\beta = 5.5$ for freeways (Martin and McGuckin, 1998); $\alpha = 0.74$ and $\beta = 5$ for arterials (TRB, 2000); $\alpha = 0.28$ and $\beta = 3.9$ for collectors (Jeihnai et al., 2006); $\alpha = 6.6$ and $\beta = 3.9$ for local roads (Jeihnai et al., 2006); and $\alpha = 0.33$ and $\beta = 3.9$ for ramps (Jeihnai et al., 2006).
Heavy Vehicle Passenger Car Equivalency	The HCM 2000's (TRB, 2000) heavy-vehicle PCE values range between 1.1 and 7.2 on freeways, depending on terrain, and are 2.0 at signalized intersections. Ingle (2004) notes PCEs range between 1.5 and 10.5 on freeways, depending on grade. PET uses a default value of 1.8.

Table B.5: Operating Costs, User Groups, and Modes

Input Name	Comments
Heavy Vehicle Operating Costs	Default value of $0.50 per mile.
Light Vehicle Operating Costs	Default value of $0.20 per mile.
Value of Time	Value of Travel Time (VOTT) for each modeled population group (in base-year $/hour).
Value of Reliability	Value of Reliability (VOR) for each modeled population group (in base-year dollars per hour of standard deviation in travel time).
% of Population	Percentage of total traveling population with given value of time and value of reliability levels.
Average Vehicle Occupancy	For each given vehicle class. Default average vehicle occupancies of 1.6 and transit average vehicle occupancy (AVO) of 12 obtained from Davis & Diegel (2007).
Mode Scale Parameter	Used in PET's travel demand model.
Mode Split Probabilities	Probability that a given user type will select a given transport mode. Note: user type 1 is assumed to be heavy-duty-truck drivers. Therefore, the model assumes a 100% probability that these travelers will not switch to other modes and that other travelers will not select heavy truck as their mode.

Table B.6: Motor Vehicle Safety Parameters

Input Name	Comments
Use Crash Costs (Y/N)	If 'Y' is selected, PET will include economic costs of crashes in the economic evaluations (B/C ratio, NPV, etc.). If 'N' is selected, changes in crash counts will be forecasted, but crashes will not be monetized.
Crash Costs (by Severity)	Default values are official 2011 USDOT recommendations. See Trottenberg and Rivkin (2011).
SPF Parameter Values	Parameter values for safety performance functions (SPFs), used in estimating crash counts. The number in the column represents the number of lanes. U is undivided, T is for two-way left-turn lane, and D is for divided median. Default values were obtained from AASHTO (2010).
Avg # Driveways per Mile	Used in crash estimates for urban and suburban arterial crashes. Default values are obtained from satellite imagery evaluations in Dallas, Houston, and Austin.

Input Name	Comments
Avg # Ramps per Mile (entrance & exit)	Used in freeway crash estimates. Default values obtained from Austin freeway ramp spacing along Loop 1, IH 35, SH 45, SH 71, SH 130, US 183, and US 290. This value is not applied if the user specifies number of entrance and exit ramps for a given freeway segment.
Rural Driveways per Mile	Used in crash estimates for rural highways.
Local and Collector Crash Rates	Rates per million VMT. Obtained from TxDOT crash statistics (2009).
Ramp Crash Rates	Per million VMT. 0.28 default obtained from average given in Bonneson and Pratt (2009). CMFs may be applied, depending on ramp configuration (as found in PET's *CMF* sheets).

Table B.7: Temperature, Emissions, and Fuel Use

Input Name	Comments
Region	Three regional data sets are available for analysis: Dallas, Waco, or Houston.
Season	Two sets of seasonal emissions data sets are available: summer or winter. Impacts are minimal, but some emissions species are at maximum levels in either extreme heat or cold, so analysts may wish to forecast for worst case emissions scenarios, based on pollutants of concern.
Use Environmental Costs (Y/N)	If 'Y' is selected, PET will include economic costs of emissions in the economic evaluations (B/C ratio, NPV, etc.). If 'N' is selected, changes in emissions will be forecasted, but not monetized.
Emissions Cost per Ton	Defaults are set to $0.
Fuel Use	Average speed-dependent fuel use in miles per gallon, based on a vehicle with an average fuel economy of 26.8 mpg.
Fuel Economy	Average fleet fuel efficiency. 'Factor' is the average fleet economy divided by the average fuel economy of the vehicle used in the *Fuel Use* table.

B.4 Operational Strategy General Parameter Information

The parameter inputs in Table B.8 are used in PET's operational strategy component.

Table B.8: Operational Strategy Parameters

Input	Comments
Project Name	
Analyst Name	
Date	
Project Life	Expected project life before replacement is necessary
Average Vehicle Occupancy	Aggregate AVO for all vehicle and user types. Default is 1.6 as per Davis and Diegel (2007).
Average Value of Travel Time	Aggregate value of travel time for all users. Default is $12 per hour. See Section 8.1 for complete description of VOTT estimation methodology.
% of Total Crashes in Hour	Default values obtained from NHTSA (2009)
Lane Blocking Incidents per Crash	Default value is 2.07, obtained from Bertini, Rose, and El-Geneidy (2005). Note: a substantial number of non-crash related incidents also occurred, resulting in the parameter value greater than 1.
Current Avg. Duration of Lane Blocking Incident	Default value of 65 minutes, as per Corbin (2006).

B.5   Required User Inputs for Developing a New Transportation Project

Default or recommended values of many input items have been suggested in the Excel sheets by PET's developers. The user can keep these default values or input updated values based on more recent or local data sources. The number of changes that the user must make is flexible, and depends on the level of detail desired and the scope of the work to be conducted. For example, developing a new and complex transportation network for a large urban area requires much more time (and more input requirements) than using a network that is already coded and modifying link capacities or tolling regimes. Tables B.9 through B.15 document the various inputs that are required, recommended for review, and useful for finer output resolution for new case studies and developing new networks, as well as listing parameters that may be reviewed.

Table B.9: Required User Inputs for New Case Studies

Input Name(s)	Comments
# Scenarios	
Initial Year	
Project Design Life	
Annual Traffic Growth Rate	
Link Info	Anything that changes from the base network
Intersection Info	Anything that changes from the base network
Total Initial Project Costs	
Additional Annual Maintenance Cost	Changes in maintenance costs for each alternative scenario as compared to the base case scenario
Salvage Value	Salvage value may be 0.
Cost - Maint. & Rehab. Project Year	If applicable. (Some projects will require interim-year maintenance or rehabilitation, particular no-build/base-case projects.)
Cost - Maint. & Rehab. Project Cost	If applicable, see above.

Table B.10: Recommended User Inputs and Parameters to Review for New Case Studies

Input Name(s)	Comments
Link info	Links in the project area that may be impacted and are not modeled in the initial network
Intersection info	Intersections on arterial links in the project area that may be impacted and are not modeled in the initial network
TOD Ref. Station Info	If ATR data is available for project specific location
Cost - Detailed Estimate Breakdown	Ex: cost per lane mi, bridges & structures, %overhead, ROW, %design, contingencies, etc.
Discount Rate	Default is 5%
Sensitivity Testing Parameter Variation	

Table B.11: Required User Inputs for New Networks

Input Name(s)	Comments
Link Info - From Node	
Link Info - To Node	
Link Info - Length (Mi)	
Link Info - Link Class	Freeway, arterial, collector, ramp
Link Info - Area Type	Urban, suburban, rural. User can set all links to a single area type if area is reasonably homogenous.
Link Info - # Lanes	
Link Info - AADT	
Link Info - Managed Lane Type	Enter 0 if the link is not a managed lane
Link Info - Land Use (Arterials Only)	Rural/residential, industrial, commercial, office. Used for crash estimation. User can set all links along a given arterial to a single land use type if arterial's development is reasonably homogenous.
Link Info - Median (Arterials Only)	None, two-way left turn lane, or restrictive. Used for crash estimation.
Link Info - Capacity	
Link Info - Capacity (By time of day if link is reversible or has variable capacity)	For managed lanes
Link Info - Tolls per Vehicle	By time of day, if applicable
Link Info - TOD Reference #	For traffic pattern distributions throughout the day. If only 1 pattern exists, enter 1 for all links.

Table B.12: Recommended User Inputs for New Networks

Input Name(s)	Comments
TOD Ref. Station Info	% traffic breakdown by TOD. Use ATR data (some default ATR data is available)
TOD Period Lengths	Defaults available or user can set period lengths/
Link Info - Link Name	Highly recommended for clarity

Table B.13: Useful Inputs for Finer Output Resolution for New Networks

Input Name(s)	Comments
Link Info - FFS (User Entered)	Default FFS will be assigned by area and link class type if link-specific FFS is not entered.
Link Info - Crash Mod Factor (CMF)	For better crash estimation resolution
Link Info - # Entry And Exit Ramps (Freeway Only)	For better crash estimation resolution
Intersection Info	For arterial intersections only, used for crash estimation. Note: the network will likely have many arterial intersections. Therefore, the analyst may want to either model only the most significant intersections or model no intersections in the base network but add new intersections in specific case studies for intersections that would likely be impacted by one or more of the proposed projects.

Table B.14: Recommended Parameters to Review for New Networks

Parameter Name(s)	Comments
Linear/Exponential Traffic Growth	Default is exponential.
Discount Rate	Default is 5%.
Default Link Free-flow Speeds	Default is 55 mph for urban freeways, 65 mph for rural freeways, 45 mph for urban arterials, and 55 mph for rural arterials.

Table B.15: Parameters that May Be Reviewed for Finer Output Resolution for New Networks and Case Studies

Parameter Name(s)	Comments
Heavy Vehicle Psg Car Equiv	Default is 1.8.
Reliability Parameters	Used to estimate travel time variance as a function of V/C ratio
Capacity Function Parameters	Used to predict speed as a function of V/C ratio
Value of Travel Time	For all user types. Default is $50/hr for trucks, $30/hr for work related trips, $10/hr for commuters, and $5/hr for personal/recreational trips.
% Population for Each User Type	Default is 10% trucks, 10% work-related trips, 20% commuters, and 60% personal/recreational trips.

Parameter Name(s)	Comments
Mode Split Probabilities	Truck driver user type assumed 100% truck mode probability. All other user classes have 68% SOV, 19% HOV2+, 9.4% HOV3+ and 3.4% transit mode split probabilities.
Operating Costs	Default $0.25/mi auto and $0.50/mi truck and transit.
Average Vehicle Occupancies	Default is 1 for SOV and Truck, 2 for HOV2, 3.2 for HOV3+ and 9 for transit.
Mode Scale Parameter	Default is 0.1. Do not alter unless analyst is proficient with logit models and understands impacts of adjusting the mode scale parameter.
Emissions Costs	Default is $0 for all species
Fuel Use by Speed	Assumes average fuel economy of 26.8 mpg. Fuel economy ranges from 10.3 mpg (at 2 mph) to 32.4 mpg (at 50 mph), then falls to 24.8 mpg (at 75 mph).
Crash Costs	Default crash costs assume economic costs only and not value of life, pain and suffering, etc. Default is $2,090 for property damage only, $41,240 for possible injury, $80,761 for non-incapacitating injury, $296,515 for incapacitating injury, and $6.2 million for fatal crashes.
Crash Severity Distribution	Defaults distributions available from Texas statewide data (2010) for rural and urban crashes.
Safety Performance Function Parameters	Default functions and parameter estimates from the *Highway Safety Manual* (2010).
Avg # Ramps per Mile	Default is 1.11 exit ramps and 1.15 entrance ramps per mile.
Rural Driveways per Mile	Default is 5 per mile.
Collector & Ramp Crash Rates	Default is 0.783 crashes per MVMT on collectors and 0.28 per million vehicles on ramps.
Demand Elasticities by TOD	Defaults are -0.5 for AM peak, -0.85 for midday, -0.45 for PM peak, -0.85 for evening, and -0.85 for off-peak periods.
TOD Scale Parameter	Default is 0.1. Do not alter unless analyst is proficient with logit models and understands impacts of adjusting the TOD scale parameter.
Fleet Makeup and Age	Default is from Texas statewide data.
Electric Vehicle Parameters	Default is 0.5% of total light vehicles/0% heavy vehicles in initial year and 10% of total light vehicles/2% of heavy vehicles in design year.

Appendix C: Toolkit Emission Structure

PET's MOVES-based emissions database contains the following six sheets:
- *Running Emissions*
- *Modified Running Emissions*
- *Starting Emissions*
- *Modified Started Emissions*
- *Average Starting Emissions*
- *Fuel Economy*

The database contains information for emission rate estimates in grams per vehicle mile (gm/mi) for the following 14 emissions species (Table C.1):

Table C.1: Emissions Species

Pollutant #	Pollutant Name
01	1,3-Butadiene
02	Acetaldehyde
03	Benzene
04	Methane (CH_4)
05	Carbon Monoxide (CO)
06	Carbon Dioxide (CO_2)
07	Formaldehyde
08	Nitrous Oxide (N_2O)
09	Ammonia (NH_3)
10	Oxides of Nitrogen (NO_x)
11	Particulate Matter with diameter $< 10\mu m$
12	Particulate Matter with diameter $< 2.5\mu m$
13	Sulfur Dioxide (SO_2)
14	Volatile Organic Compounds (VOCs)

The *Running Emissions* and *Starting Emissions* sheets are the basis of all emissions calculations and are automatically manipulated by set equations to derive the *Modified Running Emissions, Modified Starting Emissions, and Average Starting Emissions* sheets. These sheets exist almost entirely for ease of calculation and increased transparency but require no attention by typical users. "Modified sheets" simply separate emissions rates by time of day (based on hours specified in the *TOD Splits* sheet), and vehicle class. Given this separation, hourly rates are averaged for each time of day and compiled in the *Average Running* and *Average Starting Emissions* sheets. Furthermore, in the averaged sheets, for each TOD period, each vehicle type's emissions rates are multiplied by its share of the fleet (set in the *Vehicle Fleet Information* sheet X) and subsequently summed to create two vehicle classes: light and heavy.

In order to determine emissions rates for a given pollutant species, several factors must be known, including location, season, model year, vehicle type, roadway facility, vehicle operating speed, and total number of trips per time of day. If all of these factors are known, the emissions

rate can be obtained for a given pollutant species by combining the emissions rates for running and starting emissions.

Link-specific emissions are calculated in the *Emission XX YY* sheets, where *XX* is either initial year (IY) or design year (DY) and *YY* is the scenario (e.g., Base, Alternative 1, etc.). These sheets contain VMT information for light and heavy vehicle classes (used for running emissions) and total number of trips (used as a proxy for total starts and therefore as a means of calculating starting emissions). Additional descriptive information is required to pair emissions at the link level with data from the averaged sheets. Numeric lookup values are assigned to these descriptive parameters as follows in Table C.2.

Table C.2: Additional Lookup Values for Locating Emissions Rates in the Toolkit

City (C)		Season (W)		Year (Y)		Road Type (R)		Speed (S)	
1	Dallas	1	Summer	1	2010	1	Restricted	1	0 – 2.5
2	Houston	2	Winter	2	2015	2	Unrestricted	2	2.5 – 7.5
3	Waco			3	2020			3	7.5 – 12.5
				4	2025			4	12.5 – 17.5
								5	17.5 – 22.5
								6	22.5 – 27.5
								7	27.5 – 32.5
								8	32.5 – 37.5
								9	37.5 – 42.5
								10	42.5 – 47.5
								11	47.5 – 52.5
								12	52.5 – 57.5
								13	57.5 – 62.5
								14	62.5 – 67.5
								15	67.5 – 72.5
								16	> 72.5

To access the emissions lookup table values, PET uses Excel's *LOOKUP* function: *LOOKUP* (*LookupValue, LookupVector, ResultVector*). Users can do this on their own as well, if needed. Essentially, the targeted lookup value should be in the form of "$CX_cWX_wYX_YSX_SRX_RPX_P$," where X_c is the location city number, X_w is the season, X_Y is the modeled year code, X_s is vehicle operating speed category number, X_R is facility type, and X_P is the pollutant species code (as shown in the above table). Thus, for an unrestricted (arterial) link operating at 45 MPH in Dallas during the summer, the amount of running SO_2 produced for model year 2015 would be found by using the lookup value of C1W1Y2S10R2P13. Note that the pollutant number must be exactly

two digits (for example, 06 or 12), but the vehicle speed must be one digit if a single digit number or two digits if it is a two-digit number (for example, 6 or 12).

Finally, this guide provides users with the following emissions valuation tables, though users should be warned that emissions costs vary largely and that the PET default is to not monetize emissions. Table C.3 presents USDOT recommendations for costs, and Tables C.4 and C.5 present a sample of other valuations for consideration.

Table C.3: Emissions Cost Estimates (NHTSA 2010b)

Recommended Monetized Value(s)		
Emission Type	$ / long ton ($2007)	$ / metric ton ($2007)
Carbon dioxide (CO_2)	(varies)*	(varies)*
Volatile Organic Compounds (VOCs)	$1,300	$1,280
Nitrogen oxides (NOx)	$5,300	$5,217
Particulate matter (PM)	$290,000	$285,469
Sulfur dioxide (SOx)	$31,000	$30,516

Table C.4: Emissions Cost Estimates (Mailbach et al. 2008)

Air pollution costs in €/tonne of pollutant for road, rail, waterways

| Pollutant | NOₓ | NVMCC | SO₂ | Factor costs in €, 2000 prices, Unit: €2000/ t of pollutant | | | | | |
| | | | | PM₂.₅ (exhaust) | | | PM₁₀ (non-exhaust) | | |
Local environment				Urban metropolitan	Urban*	Outside built – area	Urban metropolitan	Urban*	Outside built-up areas
Austria	4,200	600	3,800	415,400	134,300	69,600	166,200	53,700	27,800
Belgium	2,600	1,100	5,200	422,200	136,200	91,100	168,900	54,500	36,500
Bulgaria	900	100	800	43,000	13,800	11,000	17,200	5,500	4,400
Cyprus	500	1,000	500	243,700	78,700	20,600	97,500	31,500	8,200
Czech Republic	3,000	1,000	3,800	252,600	81,400	62,700	101,000	32,600	25,100
Denmark	1,700	800	1,800	386,800	124,700	45,500	154,700	49,900	18,200
Estonia	1,200	400	1,000	133,400	43,400	22,500	53,400	17,300	9,000
Finland	800	200	600	337,100	108,600	28,100	134,800	43,400	11,200
France	4,400	800	4,100	392,200	126,300	78,400	156,900	50,500	31,400
Germany	3,000	1,100	4,300	384,500	124,000	75,000	153,800	49,600	30,000
Greece	2,000	600	1,300	248,700	80,100	35,000	99,500	32,100	14,000
Hungary	4,400	700	3,600	203,800	65,600	52,300	81,500	26,200	20,900
Ireland	1,800	400	1,400	391,000	126,200	40,900	156,400	50,500	16,400
Italy	3,000	1,500	3,300	371,600	120,100	67,600	148,600	48,000	27,100
Latvia	1,500	400	1,200	115,700	37,200	21,500	46,300	14,900	8,600
Lithuania	2,300	400	1,600	143,100	46,500	28,600	57,200	18,600	11,400
Luxemburg	4,400	1,300	4,500	671,500	216,200	95,700	268,600	86,500	38,300
Malta	500	1,100	500	245,400	78,700	20,400	98,200	31,500	8,200
Netherlands	2,500	1,000	4,800	422,500	136,400	82,600	169,000	54,500	33,000
Norway	1,100	300	900	309,600	99,600	30,100	123,800	39,900	12,000
Poland	2,800	700	3,200	174,500	56,000	52,400	69,800	22,400	20,900
Portugal	2,700	1,000	1,800	259,500	83,600	38,500	103,800	33,500	15,400
Romania	600	100	500	29,200	9,400	7,500	11,700	3,800	3,000
Slovakia	4,500	1,100	3,700	194,200	62,100	52,400	77,700	24,900	21,000
Slovenia	4,100	700	3,800	262,900	84,500	54,500	105,200	33,800	21,800
Spain	2,500	500	2,000	299,600	96,400	41,200	119,900	38,600	16,500
Sweden	1,200	300	1,000	352,600	113,400	34,300	141,000	45,400	13,700
Switzerland	4,400	600	3,800	444,800	143,100	73,500	177,900	57,200	29,400
UK	1,500	700	2,800	389,100	125,300	60.700	155,700	50,100	24,300

Source: HEATCO, values adjusted to € 2,000 values using GDP/cap. PPP development.

Table C.5: Emissions Cost Estimates (McCubbin and Delucchi 1996)

| Pollutant | Damage Costs ($/ton) | Adjustment Factor: | |
		Urban	Rural
Carbon Monoxide	$100	1.0	0.5
Volatile Organic Compounds	$2,750	1.5	1.0
Nirtogen Oxides	$3,625	1.5	1.0
Sulfur Dioxide	$8,400	1.5	1.0
Fine Particulate Matter (PM2.5)	$4,825	1.0	0.5
Road Dust	$4,825	1.0	0.5

MOVES Data Production

The MOVES run configuration and input datasets for PET were based on those developed by the Texas Transportation Institute (TTI) as documented in the report entitled "Development and Production of Statewide, Non-Link-Based, On-Road Mobile Source MOVES Emissions Inventory" dated July 2011 (TTI, 2011a). TTI developed hourly on-road summer (June 1–August 31) emissions for years 2006, 2008, 2012, and 2018 for typical weekday, Friday, Saturday, and Sunday day types for all 254 Texas counties. TTI's work was sponsored by the Texas Commission on Environmental Quality (TCEQ) to support future ozone attainment demonstrations for State Implementation Plan (SIP) development. Future SIP attainment demonstrations will use 2006 as the base year along with a 2008 baseline scenario. Years 2012 and 2018 were included for other air quality purposes as well as potential use in future SIP applications.

PET is designed to estimate emissions for four base years: 2010, 2015, 2020, and 2025. TTI used 2010 Texas data as the preferred basis for developing inputs for year 2012. Since several local datasets (e.g., vehicle age distributions, fuel/engine fractions, fuel formulations, I/M programs) are generally held constant in the PET MOVES applications for the four base years, the TTI MOVES dataset for 2012 served as the basis for all PET runs. Using TTI year 2012, PET incorporates information from the most recent complete year (2010), when available.

TTI developed local Texas MOVES inputs for meteorological data, fuel properties, vehicle fleet parameters, and emissions control programs. The MOVES Run Specifications (MRS) and County Input Databases (CDB) are used to specify the MOVES run configuration and non-default (i.e., local) input data, respectively. The publicly available TTI MOVES runscripts and CDB databases for year 2012 were obtained from the TCEQ website (ftp://amdaftp.tceq.texas.gov/pub/Mobile_EI/ Statewide/mvs/).

TTI modeled 22 unique combinations of MOVES Source Use Type (SUT) and fuel as shown in Table C.6. Based on the Texas fuel engine fractions, only emissions associated with gasoline and diesel fuels (which dominate on-road fuel usage) were simulated; emissions from compressed natural gas (CNG) and electricity fuel types were not considered. The SUT/fuel combinations shown in Table C.6 were also modeled in support of PET.

Table C.6: TTI Simulated Source Use Type and Fuel Combinations

MOVES SUT ID	SUT Description	Fuel Type
11	Motorcycle	Gas
21	Passenger Car	Gas and Diesel
31	Passenger Truck	Gas and Diesel
32	Light Commercial Truck	Gas and Diesel
41	Intercity Bus	Diesel
42	Transit Bus	Diesel
43	School Bus	Gas and Diesel
51	Refuse Truck	Gas and Diesel
52	Single Unit Short-Haul Truck	Gas and Diesel
53	Single Unit Long-Haul Truck	Gas and Diesel
54	Motor Home	Gas and Diesel
61	Combination Short-Haul Truck	Gas and Diesel
62	Combination Long-Haul Truck	Diesel

Generation of the Toolkit's MOVES Application

Important input variables for the PET MOVES application are briefly discussed below. The reader is referred to Kockelman et al. (2012) for additional and/or expanded discussions on the development of the MOVES configurations and inputs.

Model Year: Four model years (2010, 2015, 2020, and 2025) were simulated to support PET. MOVES2010a reflects all Corporate Average Fuel Economy (CAFE) standards through the 2011 model year car/truck standards and the 2012–2016 greenhouse gas standards finalized in 2010 (http://moves.supportportal.com/link/portal/   23002/23024/Article/32079/What-is-currently-assumed-for-future-year-fleet-fuel-efficiency).

Geographic Areas: TTI created 44 different MOVES scenarios to represent various groupings of Texas counties. The scenarios were primarily dependent on the intersections of three geographic considerations: (1) the 25 TxDOT districts used to define the SUT/fuel VMT allocations, (2) fuel regulation districts, and (3) emissions control areas. For PET's purposes, Dallas (Dallas County), Houston (Harris County), and Waco (McLennan County) were selected as representative of Texas for this initial update to PET. Waco was chosen to be representative of much of Texas outside of major metropolitan areas. Dallas and Houston, two of the largest metropolitan areas in Texas, are ozone non-attainment areas that have active Inspection and Maintenance (I/M) programs. These I/M programs were implemented to substantially reduce emissions of pollutants that participate in the formation of ozone (e.g., CO, NOx, and VOC). A cell for "Geographic area" is now included in PET, as a required input that the user must select before running PET analysis.

Meteorological Data: Temperature and relative humidity affect running exhaust emissions rates predicted by MOVES through two mechanisms: (1) directly via correction factors for NO_x and

(2) indirectly via an air conditioning adjustment—the temperature and humidity is used to calculate the heat index value, which in turn is used to predict the fraction of vehicles with in-use air conditioning (EPA, 2010b). In addition, temperature affects the rate of evaporative VOC processes as well as emissions associated with vehicle starts.

Initially, a wide range of temperature and relative humidity values were considered for input to PET. See Appendix A for a summary of sensitivity tests performed to quantify the impacts of temperature and relative humidity on emissions rates generated by MOVES.

Ultimately, the meteorological options were simplified to represent either summer or winter conditions. MOVES provides default monthly diurnal temperature and relative humidity profiles for each county in the U.S. The July average daytime (7:00 a.m. to 7:00 p.m. CST) temperature and relative humidity values for the combined counties of Dallas, Harris, and McLennan were 89F and 57%, respectively. For PET, a temperature of 90F and 50% relative humidity were specified to represent summer conditions. Similarly, the January average daytime temperature and relative humidity values for the combined counties of Dallas, Harris, and McLennan were 47F and 62%, respectively. Thus, a temperature of 50F and 60% relative humidity were specified for the winter scenario. Previously, emissions rates were available for a variety of temperature and humidity settings. However, due to MOVES run-time burdens, only two options now exist, and users must select either a summer or winter period before analysis. Future enhancements to PET could consider additional meteorological scenarios.

Road Types: MOVES calculates emissions for four on-road types as well as off-network activity. The MOVES road categories are aggregations of Highway Performance Monitoring System (HPMS) functional facility types that correspond to EPA Source Classification Codes (SCCs). Table C.7 shows the road type mapping between MOVES and HPMS.

Table C.7: MOVES Road Types Mapped to HPMS Functional Types (EPA 2010c)

MOVES Road Type	MOVES Road Type	HPMS Functional Type
1	Off Network	Off Network
2	Rural Restricted Access	Rural Interstate
3	Rural Unrestricted Access	Rural Principal Arterial, Mino Arterial, Major Collector, Minor Collector, & Local
4	Urban Restricted Access	Urban Interstate & Urban Freeway/Expressway
5	Urban Unrestricted Access	Urban Principal Arterial, Minor Arterial, Collector, & Local

Default drive cycles are used by MOVES to describe vehicle activity for each road type category. Restricted roads are accessed via an on-ramp; all other roads are captured by the unrestricted access categories. The MOVES driving cycles for unrestricted roads assume

significant stop and go driving, with multiple accelerations, decelerations, and idling. In comparison, the driving cycles for restricted access roads have relatively higher fractions of cruise activity. For restricted roads, on-ramp driving can be specified in MOVES as a fraction of the overall vehicle activity; however, as assumed by TTI, PET simulations maintained ramp activity at 0%.

Analysis of the MOVES results demonstrated that the emission rates between rural and urban roads within the same classification (i.e., either restricted or unrestricted) were similar. For example, there were no differences in emissions rates for rural and urban restricted categories for the HGB group for 2010. In contrast, some SUT/fuel/pollutant combinations were substantially different between the unrestricted and restricted categories. Based on the road type sensitivity tests (refer to Appendix A for more information), MOVES simulations were generated for only urban restricted and urban unrestricted road types so that the PET user selects either a restricted or unrestricted road type.

Pollutants: The MOVES simulations were configured to estimate emissions of 14 pollutants. The pollutants include CO, NO_x, methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), sulfur dioxide (SO_2), VOC, and CO_2, as well as the air toxic compounds acetaldehyde, benzene, 1,3-butadiene, and formaldehyde. In addition, particulate matter (PM) emissions are estimated for PM_{10} (PM with diameters less than 10 micrometers) and $PM_{2.5}$ (PM with diameters less than 2.5 micrometers).

Emissions Processes: MOVES estimates emissions from all significant vehicle activities including on-road running processes (e.g., exhaust, crankcase exhaust, brakewear, tirewear, and evaporative processes such as fuel tank venting, engine block permeation, and fuel leaks) as well as off-network emissions associated with parked vehicles (e.g., start exhaust, crankcase start exhaust, evaporative processes). Evaporative emissions from both on-road running and parked vehicles are dependent on hour of day since MOVES incorporates a number of assumptions about the vehicle fleet for each hour (e.g., the amount of time since a vehicle was last running as well as the duration of running time) that impacts predicted emissions rates. In addition, emissions associated with fuel tank venting are also dependent on the daily (e.g., 24-hour) profile of temperatures. Given the relatively long MOVES run-time (~ 2 hours per scenario using the PC-based computer resources employed for our project), only a limited number of simulations were performed to investigate evaporative emissions (summarized in Appendix A).

With the exception of evaporative emissions for VOC and benzene, on-road running processes are not dependent on hour of day. For this work, emissions were estimated for all on-road running processes including evaporation; however, evaporative emissions were estimated as a daily average of the 24 predicted hourly emissions rates. A flat (i.e., constant for all hours) diurnal temperature profile was assumed. For input into PET, emissions associated with on-road running processes were summed and provided in units of grams per VMT for each combination of SUT/fuel. Note that brakewear and tirewear processes are associated only with PM emissions.

Since PET does not explicitly simulate the entire vehicle fleet, off-network processes were limited to vehicle starts and evaporative processes were not simulated for parked vehicles. Since vehicle start emissions for all pollutants depend on hour of day, emissions were provided in units

of grams per vehicle start per hour for each combination of SUT/fuel. Off-network processes have not yet been integrated into PET since they require the total number of starts (total number of trips) as reported from the travel demand model (TDM), which is coded in C++. Dr. Stephen Boyles is currently working to provide this information as an output of the TDM so each scenario's total emissions differences (from the base case scenario) can be computed. This formatting requirement is new to PET and is a result of using MOVES instead of MOBILE (where all rates are given in terms of per mile driven). Following the C++ coding updates, the new emissions tables will be fully integrated into PET.

Note on Evaporative Emissions: The assumption of a flat temperature profile introduces uncertainty in the on-road running VOC and benzene emissions rates currently used by PET. In addition, the omission of evaporative emissions from parked vehicles means PET will under-predict area-wide emissions of VOC and benzene compared to a full MOVES simulation. Based on TTI's previous Harris County work for summer 2012 (TTI, 2011a), evaporative emissions from on-road running and parked vehicles accounted for approximately 8% and 25%, respectively, of county-wide total VOC emissions from mobile sources. The contribution from evaporative processes will be somewhat smaller for other (cooler) seasons of the year. In the case of PET applications, the impact of these evaporative emissions assumptions will be moderated by the fact that PET is designed to quantify *differences* between a base case and each alternative scenario, as opposed to predicting absolute emissions rates. Nevertheless, it would be useful to revisit the treatment of evaporative emissions in any future PET enhancements.

Age and Fuel-Engine Fraction Distributions: For the TTI 2012 MOVES simulations, age distributions (ranging from 0 years [new] to 30 years) and fuel-engine (e.g., diesel) fractions were developed using TxDOT mid-2010 county registrations data and MOVES model defaults, as needed. The age distributions were based on vehicle registration aggregations for each TxDOT district consistent with the vehicle registration aggregations used in estimating the SUT/fuel VMT mix. These data were used for each of the PET base years (i.e., 2010, 2015, 2020, and 2025) and cannot be modified by the user in the current PET. More discussion is provided in Appendix A.

Fuel Compositions: The fuel compositions are those used by TTI to generate summer and winter emissions rates in support of annual emissions trend analyses for all 254 Texas counties (TTI, 2011c). Appendix A provides the gasoline and diesel formulations used for Dallas, Houston, and Waco for the summer and winter scenarios.

It should be mentioned that the control program effects of the TxLED (Texas Low Emission Diesel) program on diesel NO_x (and other) emissions cannot be currently captured by MOVES and were not included in our work. The TCEQ estimates, for example, that TxLED fuels reduce NO_x by 4.8% and 6.2% for model years 2002 and later, and 2001 and earlier, respectively. The impact of neglecting the impact of TxLED is mitigated here since PET quantifies differences between a base case and each alternative scenario, as opposed to predicting absolute emissions rates

Vehicle Speed Bins: In the previous version of PET, emissions were reported for 14 average vehicle speed bins with a maximum speed of 65 mph. Compared to MOBILE6.2, MOVES expands the number of average speed bin categories to 16, ranging from 2.5 mph to ≥ 72.5 mph.

Description of the Emissions Rate Lookup Tables: The results from the MOVES simulations outlined above were post-processed and used to generate two individual emissions rates tables utilized by PET. One table provides on-road running emissions in units of grams per vehicle mile travelled (VMT) and consists of the following data fields: City, Season, BaseYear, Pollutant, RoadType, AverageSpeedBin, and 22 additional columns for each of the 22 SUT/fuel combinations. The second table provides data for vehicle starting emissions in units of grams per vehicle-trip per hour and has the format: City, BaseYear, Season, Pollutant, Hour (CST), and 22 additional columns for each of the 22 SUT/fuel combinations.

Appendix D: Formatting External Travel Demand Model Data for PET

In order to analyze external travel demand model data in PET, users must format data as **tab-delimited text files** in an exact format. Each text file must also be named precisely as provided below and saved in the **main PET directory.**

Naming Convention

Network Files:
 tdm_output_nw_base.txt,
 tdm_output_nw_alt1.txt,… tdm_output_nw_alt3.txt

Toll Rate Files:
 tdm_output_tolls_base.txt,
 tdm_output_tolls_alt1.txt,… tdm_output_tolls_alt3.txt

Volume Output Files:
 tdm_output_vol_base_iy.txt, tdm_output_vol_base_dy.txt,
 tdm_output_vol_alt1_iy.txt, … tdm_output_vol_alt3_dy.txt

Origin-Destination Skim Files
 tdm_output_od_alt1_iy.txt,… tdm_output_od_alt3_dy.txt

All files generated from external travel demand models to be read into PET must be tab-delimited text files. You may also refer to the sample external TDM example files, located on the PET website: http://www.ce.utexas.edu/prof/kockelman/PET_Website/homepage.htm.

Network Files

The following format should be used to create files for import as network files. These files indicate link information and network context (i.e., indicate which nodes are connected by each specific link). A maximum of 300,000 links can be imported to PET.

Rows
First 8 lines: comments or blanks
Lines 9 through end of file: each line represents one single-directional link.

Columns
In lines 9 through the end of file…
Column 1: Link Number (optional)
Column 2: From Node
Column 3: To Node
Column 4: Link Name (optional)

Column 5: Link Length
Column 6: Link Classification
Column 7: Area Type
Column 8: # of Lanes
Column 9: Land Use (required for arterials only)
Column 10: Median Type (required for arterials only)
Column 11: Link Capacity

For coding descriptions for link classification, type, land use, and medians, see Section 2.6 or the example TDM Output Network file.

Toll Rate Files

If toll rate files are used, the number and ordering of links must match exactly those used in the TDM Output Network files. This file is arranged with five times of day (default: AM Peak, Midday, PM Peak, Evening, and Off Peak) and five vehicle classes (Default: SOV, HOV2, HOV3+, Transit, Heavy Truck), with each vehicle class potentially paying a different toll at varying times of day. Analysts do not need to use all times of day and/or all vehicle classes, and non-tolled links may be left blank. If less than five vehicle classes or times of day are used, begin by leaving vehicle class #5 or time of day #5 blank, then #4, etc. until the proper number of vehicle classes or times of day are present.

Rows
First 4 lines: comments or blanks
Lines 5 through end of file: each line represents one single-directional link.

Columns
In lines 5 through the end of file…
Column 1: Link #
Column 2: AM Peak Vehicle Class 1
Column 3: AM Peak Vehicle Class 2 …
Column 6: AM Peak Vehicle Class 5
Column 7: Midday Vehicle Class 1…
Column 11: Midday Vehicle Class 5…
Column 26: Off Peak Vehicle Class 5

Volume Output Files

The number and ordering of links must match exactly those used in the TDM Output Network files, and volumes (total number of vehicles in each period) must correspond to vehicle class and TOD tolling specifications used in the TDM Output Toll Rate files.

Rows
First 4 lines: comments or blanks
Lines 5 through end of file: each line represents one single-directional link.

Columns
In lines 5 through the end of file…
Column 1: Link #
Column 2: AM Peak Vehicle Class 1
Column 3: AM Peak Vehicle Class 2 …
Column 6: AM Peak Vehicle Class 5
Column 7: Midday Vehicle Class 1…
Column 11: Midday Vehicle Class 5…
Column 26: Off Peak Vehicle Class 5
Column 27: AM Peak link speed (mph) …
Column 31: Off Peak link speed (mph)

Origin-Destination Skim Files

Maximum number of O-D pairs: 1,000,000

Row 1, Column 2: Number of user classes with different values of travel time

Row 2, Column 2: Number of O-D pairs

Row 4, Columns 2 – 11: Values of travel time ($/hr) for user classes 1…n

Rows
Lines 3, 5 and 6: comments or blanks
Lines 7 through end of file: each line represents one origin-destination pair.

Columns
In lines 7 through the end of file…
Column 1: Origin node
Column 2: Destination node
Column 3: Time of Day
Column 4: User Class 1 volume (veh./period)
Column 5: User Class 1 travel cost ($/veh.)
Column 6: User Class 1 travel time (min.)
Column 7: User Class 2 volume (veh./period)
Column 8: User Class 2 travel cost ($/veh.)
Column 9: User Class 2 travel time (min.)…

Appendix E: Trip Table Formulation

This section describes the mathematical formulations used in the updated PET trip table estimator. Its focus is on the formulation and "high-level" algorithm logic; details of the solution method chosen for solving nonlinear programs and performing logit trip assignment are left to Bertsekas (1999) and Dial (1971).

The objective of this procedure is to identify a trip table for a transportation network, given observed link volume counts. This problem is notoriously difficult for several reasons. First, it is undetermined: in a network with n nodes and m links, the trip table has dimension $O(n^2)$, while volume counts are available on $O(m)$ links. In transportation networks, m is usually $O(n)$, so there are far more variables than equations, leading to infinitely many trip tables that could satisfy the link counts. A procedure must be developed to select among this infinity of solutions.

The second challenge relates to the accuracy of the link counts. Whether due to device error, temporal effects (most seriously when volume counts are not all obtained at the same time, but can arise around the start and end of the recording periods even when all measurements are contemporaneous), trips turning into or out of driveways mid-link, or other reasons, it is often unwise to try to match the counts *exactly*, as the true values of these data are unknown. Practically speaking, a worse problem arises in networks where each node can serve as an origin and destination: in such networks, there is a trivial but highly unrealistic solution, in which all trips travel from one node to an adjacent node (if the observed volume on link (i, j) is x_{ij}, then the demand from node i to node j is also x_{ij}; the demand between any nonadjacent nodes is zero). This trivial solution is found very often by simple algorithms, and a more careful approach is needed.

The method below uses a "target" trip table with a more plausible geographic spread, and applies a least-squares approach to trip table generation, in which we seek a solution that closely approximates both the target trip table and the link volumes simultaneously. This target trip table is obtained by a simple gravity model, but the method is "modular" and another methodology for generating the target trip table is easily accommodated. All trip table estimation procedures must assume some assignment logic to decide which links will be used by the demand between two nodes; a stochastic user equilibrium (SUE) approach is used here, for reasons discussed in more detail below.

From a very high level, the user specifies (a) the network topology; (b) the observed volumes on some or all links; and (c) the maximum average deviation from observed volumes permitted when the trip table sought is assigned using SUE. The code returns this trip table, as well as the SUE logit parameter that fits the link counts best. The following sections present the basic formulation, followed by discussion of the target trip table methodology, the link with SUE, and the procedure used to identify the best value of the logit parameter. The last section provides pseudocode for the entire algorithm; however, the most important components are presented first.

Basic Formulation

Consider a network $G = (N, A)$ with node and arc sets N and A, respectively. Let $Z \subseteq N$ be the set of "zone" nodes that can serve as origins and destinations, and let $\overline{A} \subseteq A$ be the set of links for which volume counts are available. The $|Z| \times |Z|$ matrix D is the calculated trip table, where d^{rs} represents the number of trips from origin r to destination s. This is the primary output of the algorithm.

Let x_{ij} denote the predicted volume on link (i, j) based on the trip table D, and let $\overline{x}_{ij}$ denote the observed volume count on link $(i, j) \in \overline{A}$. Similarly, the target trip table is denoted $\overline{D}$ with entries $\overline{d}^{rs}$. The assignment logic is described using the parameters η_{ij}^{rs}, which represent the proportion of demand from origin r to destination s, which will use link (i, j). With this notation, the least-squares procedure can be formulated as the nonlinear program expressed in Equations E.1–E.4.

$$\min_{\mathbf{D},\mathbf{x}} \quad \sum_{(r,s) \in Z^2} \left(d^{rs} - \overline{d}^{rs} \right)^2 \qquad\qquad (E.1)$$

$$\text{s.t.} \quad x_{ij} = \sum_{(r,s) \in Z^2} \eta_{ij}^{rs} d^{rs} \qquad \forall (i,j) \in A \quad (E.2)$$

$$\sum_{(i,j) \in \overline{A}} e_{ij}\left(x_{ij}, \overline{x}_{ij} \right) \le M \qquad \forall (i,j) \in \overline{A} \quad (E.3)$$

$$d^{rs} \ge 0 \qquad\qquad \forall (r,s) \in Z^2 \quad (E.4)$$

where M is the maximum allowable deviation from the volume counts, and e_{ij} is a distance metric. Different choices of e_{ij} constrain deviation differently: $e_{ij}\left(x_{ij}, \overline{x}_{ij} \right) = \left| \overline{x}_{ij} - x_{ij} \right|$ measures total absolute deviation, while $e_{ij}\left(x_{ij}, \overline{x}_{ij} \right) = \dfrac{1}{m} \left| \dfrac{x_{ij}}{\overline{x}_{ij}} - 1 \right|$ measures average percent deviation. Both of these choices result in a convex constraint set that pose no significant difficulties in solution.

This nonlinear program can be solved by substituting constraint (2) into constraint (3), and applying a standard Lagrangianization algorithm (at present, the augmented Lagrangian algorithm described in §4.2 of Bertsekas, 1999).

Identifying the Target Trip Table

This section describes the current method for calculating the target trip table. It should be emphasized that this methodology can be changed without affecting solution of the nonlinear program (1)–(4) in any way whatsoever (it simply changes the values of parameters in the objective function). It should also be emphasized that this procedure is highly approximate, and is not intended to produce an accurate trip table (after all, if we had the data and resources needed to do that, there is no need to apply the methodology in this document at all). Rather, the

intent is simply to guide the solution algorithm to a "reasonable" solution, away from the trivial solution of unrealistically short zone-to-adjacent-zone trips.

The current code uses a simple gravity model, which begins by calculating zonal productions P^r and attractions A^s for each origin r and destination s:

$$P^r = \xi_P \sum_{(r,j) \in A} \overline{x}_{rj} \quad \forall r \in Z$$

$$A^s = \xi_A \sum_{(i,s) \in A} \overline{x}_{is} \quad \forall s \in Z$$

These calculations are based on the total outgoing or ingoing flow, multiplied by a scale parameter. (The use of different scale parameters for productions and attractions may be needed to ensure that total productions equal total attractions.) This methodology works in networks where volume counts are available on all links (i.e., when $\overline{A} = A$), since productions and attractions are based on these observed volume counts. It is unable to provide production and attraction estimates in regions of the network without volume counts, and a different procedure should be applied in such cases.

Given friction factors ϕ^{rs} between each origin and destination (perhaps based on shortest path travel times) the trip table is given by

$$d^{rs} = \frac{\mu_s P^r A^s \phi^{rs}}{\sum_{s' \in Z} \mu_{s'} P^r A^{s'} \phi^{rs'}}$$

where the μ are chosen such that

$$\sum_{r \in Z} d^{rs} = A^s$$

for all destinations s. An iterative balancing procedure converges rapidly to the correct μ values.

Appropriate "default" choices of the production and attraction scale parameters and friction factors will be calibrated using results from test networks.

Determining Link Usage Factors

This section describes how the link usage factors η_{ij}^{rs} are calculated. These factors are calculated as a preprocessing step, before the nonlinear program (1)–(4) is solved. The calculation is relatively straightforward, and based on Dial's STOCH algorithm (1971) for logit assignment on networks with fixed travel times. First, travel times for each link are obtained by substituting the observed volume count on each link into its link performance function. (If counts are not available on all links, a reasonable estimate can be made of the link's travel time, using the free-flow time if no better estimate is available.) Next, STOCH is applied once for each OD pair, assigning a single unit of demand from origin r to destination s. The resulting link flows are exactly the η_{ij}^{rs} values corresponding to this OD pair.

These values specify the proportion of demand that will use a particular link, when assigned according to the logit principle underlying SUE. Since this assignment uses a logit model, the

dispersion parameter θ must be specified. This parameter can either be pre-specified, or calculated internally using a line search, as discussed in the next section.

As an implementation note, computational savings can be obtained by first performing one-to-all shortest paths from each origin, and noting the "bush" of zero reduced-cost links corresponding to this origin. Dial's algorithm is efficient, and this preprocessing step does not consume excessive time.

Choosing an Appropriate Logit Factor

The final piece of the trip table estimation procedure involves choosing an appropriate logit dispersion parameter θ. As this parameter varies, so will the link usage parameters and the objective function (1); let $z(\theta)$ denote the optimal value of (1) using link usage parameters obtained from θ. Since z is a function of a single variable, a line search procedure (such as the well-known golden section search) can be used to find a minimum, which corresponds to the logit dispersion parameter that provides the best fit to the target trip matrix, given the constraint of approximating the observed volume counts.

Unfortunately, this function may not be convex or even unimodal, so this minimum may be only a local minimum. However, for the purposes of PET, even a local minimum should yield a useful trip table. This line search frames the "master problem" for the entire algorithm, which can be specified as follows.

Step 1. Choose a set Θ of dispersion parameters to test (three for golden section search)

Step 2: Choose a dispersion parameter θ in this set for which $z(\theta)$ is unknown, and calculate link usage parameters using STOCH.

Step 3: Calculate $z(\theta)$ by solving the nonlinear program (1)-(4)

Step 4: If there are still values in Θ for which $z(\theta)$ is unknown, return to step two.

Step 5: Generate a new dispersion parameter using the known $z(\theta)$ values, add it to Θ, and return to step two.

This algorithm can be efficiently implemented using a linked-list data structure.