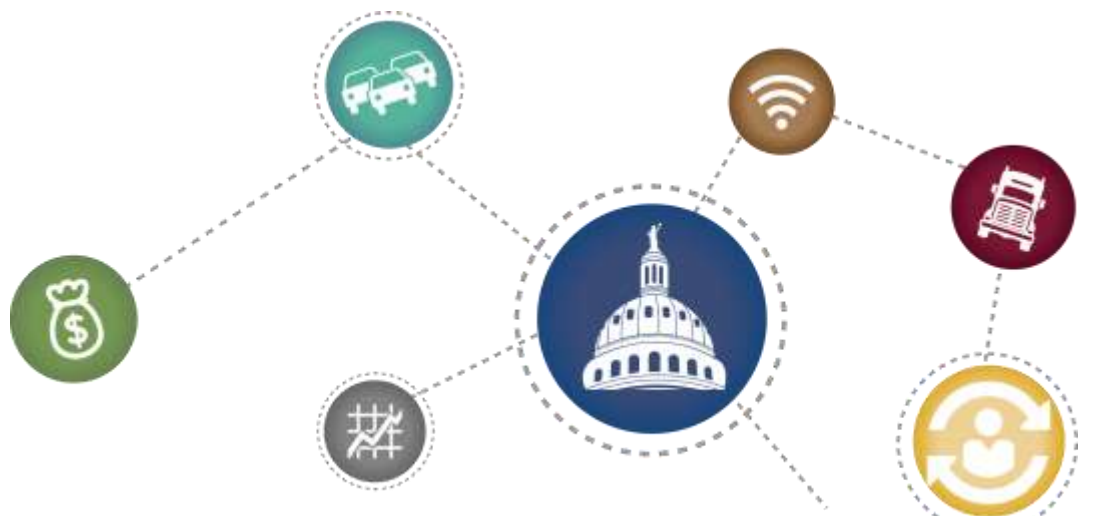


Estimating Congestion Benefits of Transportation Projects with FIXiT 2.0: Updating and Improving the Sketch Planning Tool

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Estimating Congestion Benefits of Transportation Projects with FIXiT 2.0: Updating and Improving the Sketch Planning Tool

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Estimating congestion benefits of transportation projects with FIXiT 2.0

Transportation agencies face continual pressure to ensure the proper allocation of transportation investments and financial resources. Choosing the right set of congestion mitigation and mobility strategies is critical to ensuring the wise application of these funds. Texas A&M Transportation Institute researchers developed the Future Improvement Examination Technique (FIXiT) sketch planning tool to assist in making those choices. This report describes an updated version of the FIXiT tool, improved to make it more responsive and simpler to use.

- FIXiT 2.0 uses a variety of data sources to calculate a magnitude value or congestion reduction benefits.
- The updated version consists of two distinct parts: developing a master table of recommended delay reduction benefits for each congestion mitigation strategy based on observed information, and simplifying the tool's algorithms to integrate this new methodology.
- The benefit calculation process involves:
 - Input of travel delay data.
 - Selection of strategies.
 - Calculation of benefits by road segment and urban area.
 - Reporting of benefits.
- Through its updated process, FIXiT 2.0 can report unbiased benefits that one or a package of congestion mitigation strategies may provide to a specific corridor or broader geographic area.
- The updated version allow for several uses, including:
 - Project-to-project comparisons, adding an evidence-based rationale for the selected choice.
 - Project justification and strategy education, to clarify the benefits of a project or strategy selection.
 - Alternative project scenario selection, comparing strategies or combinations of strategies to determine the effect on the same study area.
 - Goals to practice, allowing communities to link mobility plans with actions.
 - Agency cooperation, allowing for greater effects than could be achieved by a single agency.
 - Standard setting through performance goals, providing an accountability method for an area to qualify for grants or federal funding.
- Researchers note that outputs from the tool constitute ranges that are estimates, and that the results from using the tool should not be applied as a final factor in determining transportation project prioritization, but instead should be used as an early screening tool in conjunction with a series of factors when allocating funding and prioritizing projects for an area.

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Executive Summary

Transportation agencies continue to face financial challenges and remain under pressure from decision makers and the public to ensure proper allocation of transportation investments and financial resources. Funds to address mobility issues and increase system reliability are limited. In some cases, the inability to increase capacity to address congestion means transportation agencies must plan ways to increase the efficiency of the road network system through innovative techniques. Choosing the right set of congestion mitigation and mobility strategies is critical to ensuring wise expenditure of state funds, giving the greatest benefit per dollar.

Sketch planning tools allow planners and decision makers to calculate “back of the napkin” estimates of project benefits for different strategies. In 2011 and 2012, the Texas State Legislature tasked the Texas A&M Transportation Institute (TTI) to estimate the congestion benefits of several projects, spurring the development of the Future Improvement Examination Technique (FIXiT) sketch planning tool. Since this original effort, the tool has been used multiple times for the Transportation Commission, the Texas Department of Transportation (TxDOT), and other regional partners to give rough estimates of strategy and project congestion benefits.

Approach

After several years of use, researchers sought to update the tool, giving it additional functionality missing from other similar sketch planning tools and simplifying the algorithms to make it more responsive and simpler to use. For this research, researchers improved upon the previous FIXiT tool, which provided an economic evaluation and identified congestion reduction/mobility improvement and financial/economic benefits compared to a project’s cost.

Researchers found the need to update the tool because FIXiT 1.0 was limited to examining a small set of the total universe of congestion mitigation strategies and only one strategy at a time. Without the ability to combine congestion mitigation and mobility strategies into a single package, the tool cannot provide an accurate estimate of mobility and congestion benefits. Additionally, the original version, like many other sketch-planning tools available, is incredibly complex and needlessly complicates many portions of the calculation in order to provide outputs that are more detailed. This is a confirmed trend as none of the current performance-based planning and operation tools like FIXiT, reported in the literature search, can perform these tasks at a macroscopic (regional) and mesoscopic (corridor) level while providing a simple user experience.

The updates to the tool will allow for better:

- Project-to-project comparisons.
- Project justification/strategy education.
- Alternative project scenario selection.
- Goals to practice.

- Agency cooperation.
- Standard setting through performance goals.

Analysis

Initial efforts by researchers began by attempting to reconfigure the existing model to add a layer of complexity that would address the limitations. However, researchers quickly scrapped this effort because the added complexity made the tool unusable. Researchers reassessed the conceptual processes and developed a much simpler model, realizing that the original model needlessly performed calculations to obtain data that was already available and converted benefits into a difficult format.

These conceptual realizations shifted the tool's conceptual base towards a simpler idea: determine the delay reduction for each congestion mitigation strategy and multiply that by the known delay on a roadway or in a region. This concept dramatically simplifies the tool, enables multiple strategies to be calculated at once, and allows the tool's results to be based on observed data from before/after studies for each congestion mitigation strategy.

The update, then, is composed of two distinct parts: 1) developing a master table of recommended delay reduction benefits for each congestion mitigation strategy based on observed information, and 2) simplifying the tool's algorithms to integrate this new methodology.

As part of the redevelopment process of the tool, a new table was developed to categorize and better understand the benefits of each congestion mitigation strategy. The table was broken down into seven categories:

- Area.
- Congestion Strategy.
- Congestion Strategy Sub-category.
- Geographical Impact.
- Impact Findings.
- Delay Measure.
- Percent Recommendation.

This new table serves as the fundamental foundation for the updated tool, as it identifies the recommended benefits for an area for each congestion mitigation strategy. The table further identifies the geographical area the strategy is applicable to, as not every strategy is relevant at a corridor or regional scale (e.g., it is difficult and pointless to estimate telecommuting's benefit to a particular corridor as it is most applicable to a regional assessment).

To justify the recommended congestion benefits, the research team completed a thorough literature review of before-and-after studies of congestion benefits from the implementation of

strategies throughout the nation and world. With this and expert knowledge, a conservative value was applied in the tool to help calculate the overall benefit of a strategy.

Tool Development

The FIXiT tool uses a variety of data sources to calculate a magnitude value of reduction benefits. Many aspects from previous working models were selected to improve the FIXiT 2.0 model, and this is represented as an overview in Figure 1.



Figure 1. Calculation Process for FIXiT 2.0.

The tool uses input data of peak period annual hours of delay, off-peak annual hours of delay, and weekend annual hours of delay for each individual segment in TxDOT’s *Texas 100 Most Congested Roadways* dataset, based on the urban area being analyzed. From there, congestion mitigation strategies are selected based on the categorized table mentioned above. The tool uses segment delay reduction benefit values for six scenarios:

- Total Delay Low Scenario.
- Total Delay High Scenario.
- Recurring Delay Low Scenario.
- Recurring Delay High Scenario.
- Non-recurring Delay Low Scenario.
- Non-recurring Delay High Scenario.

The tool calculates delay reduction benefits by segment and by urban area. To calculate the delay reduction benefits for the urban area, the tool uses three benefit values:

- Total Delay.
- Recurring Delay.
- Non-recurring Delay.

The tool reports delay reduction benefits for each segment, based on low scenario (the least amount of benefit) and high scenario (the most amount of benefit).

Conclusions

As the state continues to grow and roadway infrastructure continues to experience strain and pressure from this growth, finding the appropriate mix of congestion mitigation and mobility strategies to provide a holistic and robust transportation network will be crucial. Finding ways to spend limited state resources wisely in order to obtain the biggest benefit will continue to be a priority at every level of the planning process, but ensuring early on that rough cost and benefit estimates meet expectations will be crucial.

This update to the FIXiT tool will allow a sketch-planning process that is responsive to the needs of the State Legislature, as well as to regional partners and planning officials. Through the updated process, FIXiT 2.0 can report unbiased benefits that one or a package of congestion mitigation strategies may provide to an area or corridor.

Users of the results from the tool should remember that outputs are ranges that are still estimates based on comparable findings. During the update process, researchers designed the tool to provide conservative estimates where possible to understate the potential benefit of a strategy in order to manage potential expectations from a project.

The results of the tool should not be used as a final factor in determining project prioritization, but should be used as an early screening tool in conjunction with a series of factors when allocating funding and prioritizing projects for an area.

Introduction

In 2011, the 82nd Texas Legislature recognized that the most congested highways in the state of Texas were costing the state more than \$10 billion per year in lost time and wasted fuel. Seeing the urgency of this problem in light of Texas' continued growth, the Legislature set aside \$300 million for fiscal years 2012 and 2013 to “acquire right of way, conduct feasibility studies and project planning, and outsource engineering work for the most congested roadway segments in each of the four most congested regions of the state as listed in the State's Top 100 Most Congested Roadways as of January 1, 2011”¹.

The Mobility Investment Priorities (MIP) project was developed as a partnership between the Texas Department of Transportation (TxDOT), local transportation and planning entities, and the Texas A&M Transportation Institute (TTI) to facilitate and coordinate a process to advance projects that will significantly improve mobility and strengthen the economy in the Austin, Dallas-Fort Worth, Houston, and San Antonio metropolitan areas. This effort worked to identify high-impact congestion relief projects that are not fully addressed in local transportation plans and that provide the biggest ‘bang for the buck’ with state transportation funding.

During the MIP project, TTI developed the FIXiT tool to work in coordination with TREDIS, a transportation economic evaluation tool. FIXiT, used in conjunction with TREDIS, can provide both congestion reduction/mobility improvement and financial/economic benefits compared to a project's cost. This high-level cost-benefit analysis is important to narrowing a set of projects early in the planning process to ensure taxpayer funds are spent wisely and efficiently. This method of examination, known as performance-based planning and operation, is a technique being adopted that identifies projects that meet state and local transportation needs while being mindful of taxpayer investment.

Value of the Tool

While FIXiT was developed for a specific use case, the tool is limited to examining a small set of the total universe of congestion mitigation strategies and cannot examine multiple congestion mitigation and mobility strategies that are combined into a package. To date, none of the other performance-based planning and operation tools similar to FIXiT can perform this task at a macroscopic (regional) or mesoscopic (corridor) level either. However, adding this functionality will greatly increase FIXiT's reach into the type and scale of projects and mobility packages that can be analyzed. Additional improvements to the methodology will also increase this ‘back-of-the-envelope’ accuracy when discussing projects at different scales.

Updates to FIXiT will allow for several uses, including:

- *Project-to-Project Comparisons*: The tool provides comparisons between various study areas (road segments or urban areas) to determine which strategy will have the greatest

¹ General Appropriations Act, TX H.B. 1, Rider 42, 82nd Legislature, 2011

positive impact to a problem area and enable an informed decision about which projects should be funded first. The process will help eliminate potential bias and add an evidence-based rationale to the selected choice.

- *Project Justification/Strategy Education*: The tool provides a basis for justification and clarification of the benefits a project or set of mobility strategies will bring to a corridor or region.
- *Alternative Project Scenario Selection*: The tool will compare various strategies or combinations of strategies to determine the effect on the same study area (segment or urban area).
- *Goals to Practice*: Often agencies set goals for their community but are unable to see those goals become reality due to lack of funding or direction. Through the benefit estimation process, communities will be able to plan efficiently with step-by-step action to utilize resources most efficiently.
- *Agency Cooperation*: The tool may facilitate interagency cooperation by allowing multi-pronged approaches that span different agencies to be assessed at the same time. Through agency cooperation, area-wide strategies and programs can be implemented in a region and monitored by a group of agencies. This strategy has a greater effect than a single agency trying to implement and monitor mitigation measures.
- *Standard Setting through Performance Goals*: The tool provides an accountability method for an area to qualify for grants or federal funding that may have only been attainable by reaching a certain threshold. Understanding how different strategies benefit a region may help decision makers to use limited resources in the most efficient way possible.

State Legislators may find additional benefit in the tool as it may provide them with knowledgeable information to enact policy and appropriate funds that better meet the goals and objectives of the state. The FIXiT tool could help ensure Texas' resources are being used efficiently and in turn instill confidence that taxpayer dollars are being wisely spent.

In response to the State of Texas facing massive growth, innovative methods and tools must be developed to mitigate the state's growing pains. Transportation agencies will continually face financial constraints, and agencies must invest and allocate restricted resources prudently. With this mindset, the Legislature, regions, and cities will be able to improve the quality of life and economic competitiveness of Texas metropolitan regions in a more resourceful manner.

Purpose of Report

The objective of the project is to update the previous FIXiT tool to estimate the congestion benefits of transportation projects by using simplified methodology, while focusing on different types of delay reduction and multiple congestion mitigation strategies.

Previous Tools and Efforts

Transportation agencies have and will continue to face financial challenges and are under pressure from decision makers and the public to ensure transportation investments and financial resources are allocated prudently. Sketch-planning tools for cost-benefit analysis are a way to provide transportation agencies guidance during the project/program screening and prioritizing process. Four sketch-planning case studies were examined to understand and provide background on the guidance provided for transportation practitioners during the project/program screening and prioritizing process: Trip Reduction Impacts of Mobility Management Strategies (TRIMMS), Transportation Efficiency Analysis Model (STEAM), ITS Deployment Analysis System (IDAS), and Highway Economic Requirements System - State Version (HERS-ST).

A key finding from the analysis of sketch-planning tools is that all tools use simplified techniques and aggregated data to perform analysis for all phases of the transportation planning process. A brief overview of the key characteristics for each of the case studies follows:

- Trip Reduction Impacts of Mobility Management Strategies (TRIMMS[®]) model:
 - 1) The scope of the tool allows it to quantify the impacts of various transportation demand management (TDM) strategies.
 - 2) Capability to allow the customization for numerous input parameters.
 - 3) Ability for the tool to differentiate the analysis at various levels.
 - 4) Flexibility of the tool to be implemented by transportation agencies across the country.
- Transportation Efficiency Analysis Model (STEAM):
 - 1) An enhanced version of the Sketch Planning Analysis Spreadsheet Model (SPASM).
 - 2) Focuses on the multimodal analysis at the regional and corridor level.
 - 3) Scope to estimate system-wide impacts.
 - 4) Capability of the tool to accept inputs and post-process outputs from the conventional four-step travel demand model or from other software.
 - 5) Ability for the tool to perform risk analysis to indicate the level of uncertainty to minimize the potential for unproductive technical controversy over unit monetary values or impact estimates (*I*).

- Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS) model:
 - 1) The scope of the tool allows it to evaluate the costs and benefits of various ITS components.
 - 2) Compatibility of the tool to integrate with the leading travel demand models.
 - 3) Capability of the tool to use readily available data.
 - 4) Ability of the tool to be updated progressively at a cost-effective price.
- Highway Economic Requirements System - State Version (HERS-ST) model:
 - 1) The scope of the tools allows it to evaluate the costs and benefits of various highway capital improvements.
 - 2) Compatibility to be integrated with the graphical information system (GIS).
 - 3) Capability to use Microsoft Windows as a base application (2).

An in-depth literature review of each of the case studies will review the current state-of-the-practice related to sketch-planning tools. These case studies will help guide the development of the FIXiT tool.

Case Study #1: Trip Reduction Impacts of Mobility Management Strategies (TRIMMS[®])

Funded by the Florida Department of Transportation and the U.S. Department of Transportation, the Trip Reduction Impacts of Mobility Management Strategies (TRIMMS[®]) model was developed by the National Center for Transit Research (NCTR) at the Center for Urban Transportation Research (CUTR), University of South Florida (3).

TRIMMS[®], is a spreadsheet-based visual basic (VB)-programmed sketch-planning tool that quantifies the impacts of a wide range of TDM strategies. The model includes a sensitivity analysis module that provides a program cost-effectiveness assessment, such as net program benefits and benefit-to-cost ratio indicators. This feature allows the model to conduct project/program evaluations to meet the Federal Highway Administration Congestion and Air Quality (CMAQ) Improvement Program requirements for project/program effectiveness assessment and benchmarking (3,4).

The TRIMMS[®] model evaluates the trip reduction impacts of TDM strategies. Changes in societal or external costs are estimated based on changes in travel behaviors (mode shares and trip length) and compared to the baseline case scenario. Externalities used in the TRIMMS[®] Model include air pollution emissions, added congestion, excess fuel consumption, global climate change, health and safety, and noise pollution (3). Figure 2 depicts the internal structure of the TRIMMS[®] model (5).

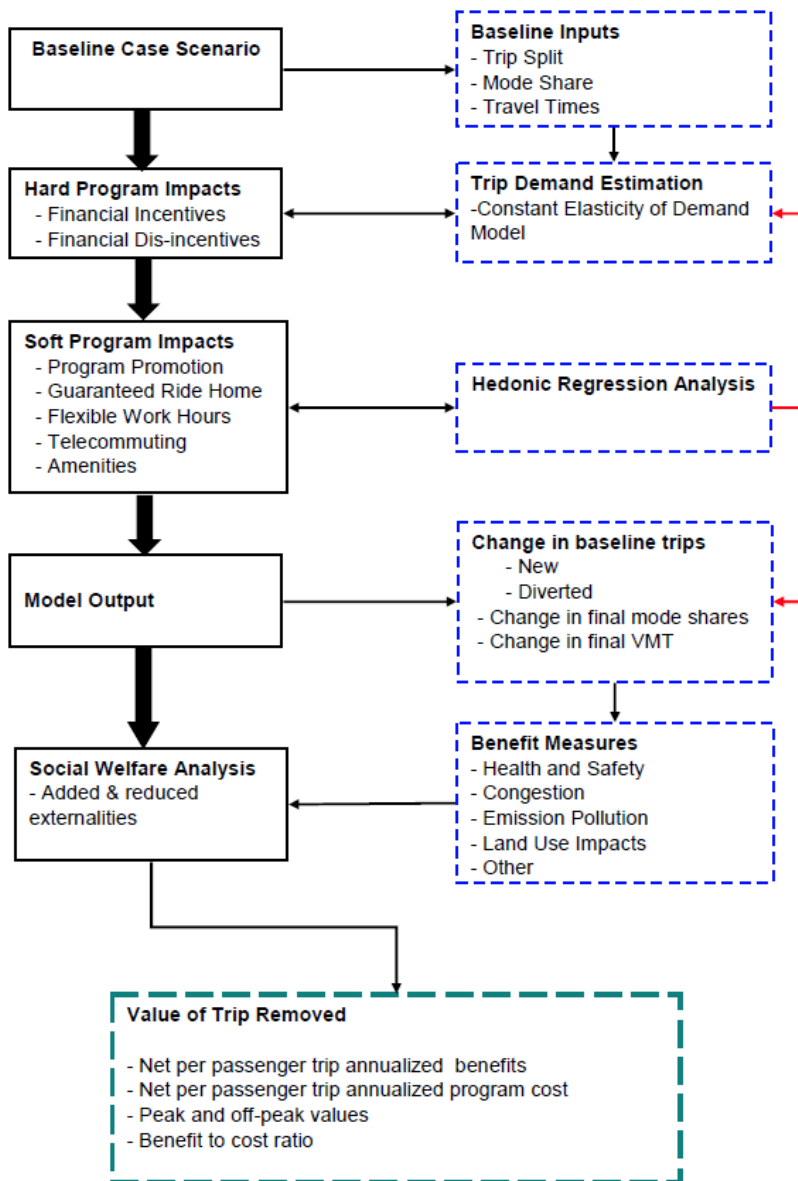


Figure 2. TRIMMS© Model Internal Structure.

A new version, TRIMMS[®] 2.0, an updated version from the previous model, was released recently by the research team and is run on the Microsoft Excel[®] platform. This spreadsheet-based model “reduces the number of steps required to conduct the project/program evaluation and accommodates the expanded disaggregation of the model parameters” (3). When launching the model, a welcome interface pops up and activates the Introduction worksheet containing a Run Analysis button and a User Manual button.

The Run Analysis button launches a module consisting of an 11-step process leading to the completion of project/program evaluation process (3):

- Step 1 – Analysis Description and Scope.
- Step 2 – Geographical Area Selection.
- Step 3 – Program Details.
- Step 4 – Baseline Mode Shares and Trip Length.
- Step 5 through Step 9 – Employer Support Program Evaluation.
- Step 10 – Financial and Pricing Strategies Evaluation.
- Step 11 – Access and Travel Time Improvements Evaluation.

The baseline case scenario defines the status of a project /program without the implementation of the proposed TDM strategy. Input parameters needed to define the baseline case scenario include (5):

- Program Information on the base case scenario, where program characteristics are described.
- Individual Information on the number of users the policy will affect. Usually composed of a pool of employees participating as part of a TDM program.
- Trip Data, information on mode shares, average trip length and travel time by mode, and average vehicle occupancy.

The Finish button, on the TRIMMS[®] 2.0 model performs the analysis and is then displayed on the Results worksheet. The TDM strategies being evaluated are summarized, and their impacts associated with trip reduction are presented using the evaluation metric of choice (3). Figure 3 shows the Results worksheet of the TRIMMS[®] 2.0 model (3).

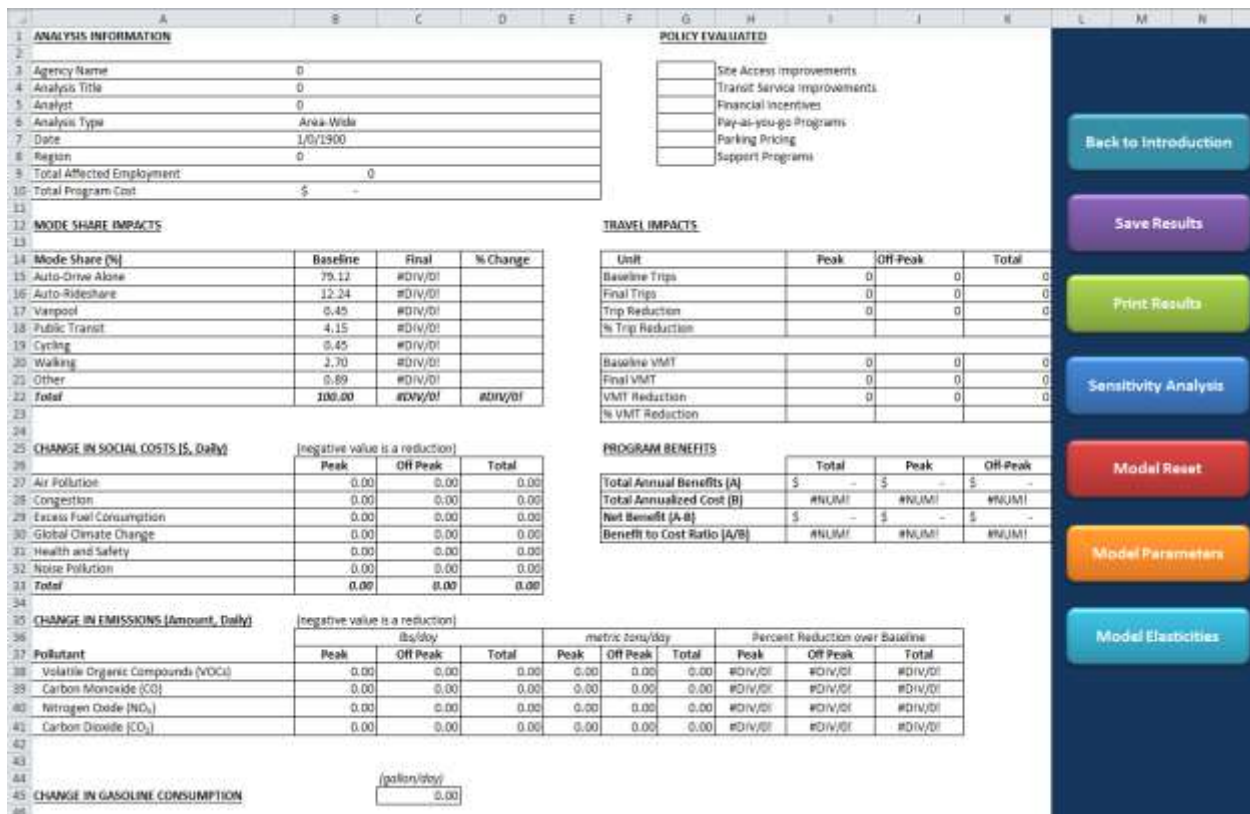


Figure 3. TRIMMS[®] 2.0 Model Results Worksheet.

The TRIMMS[®] 2.0 model provides a comparative assessment of TDM strategies for transportation agencies to make informed decisions. Finite transportation dollars are allocated based on the comprehensive project/program evaluation results. The key characteristics of the TRIMMS[®] 2.0 model include:

- 1) The scope of the tool allows it to quantify the impacts of various transportation demand management (TDM) strategies, but no other mitigation strategies.
- 2) Capabilities allow the customization of numerous input parameters.
- 3) Ability for the tool to differentiate the analysis at various levels.
- 4) Flexibility of the tool to be implemented by transportation agencies across the country.

While this model does produce detailed information, it is limited to a small set of project types and cannot be easily integrated with multiple strategies.

Case Study #2: Transportation Efficiency Analysis Model (STEAM)

Funded by the Federal Highway Administration (FHWA), the Surface Transportation Efficiency Analysis Model (STEAM) is a sketch-planning tool developed by Cambridge Systematics (6).

STEAM is designed for transportation agencies at the state and regional level and assesses multimodal transportation infrastructure and policy alternatives related to travel demand.

Prior to STEAM, FHWA's early efforts date back to the 1990s. A Cost-Benefit Analysis (CBA or Benefit-Cost Analysis, BCA) tool was developed and included the Sketch Planning Analysis Spreadsheet Model (SPASM), a spreadsheet for use in multimodal analysis at the corridor level (7).

STEAM is an enhanced version of SPASM and focuses on multimodal analysis at the regional and corridor level. Significant improvements to STEAM include:

- Scope enhancements to estimate system-wide impacts.
- The capability to accept inputs and post-process outputs from the conventional four-step travel demand model or from other software packages.
- The ability to perform a risk analysis to indicate the level of uncertainty, which minimizes the potential for unproductive technical controversy over unit monetary values or impact estimates (1).

Default analysis parameters in STEAM include multi-modal transportation systems incorporating up to seven modes (auto, carpool, truck, local bus, express bus, light rail, and heavy rail) (8). Non-default modes can be accommodated through custom user modification. STEAM consists of four modules (1, 6):

- User Interface Module.
- Network Analysis Module.
- Trip Table Analysis Module.
- Evaluation Summary Module.

In the Evaluation Summary Module, benefit categories considered in STEAM include (8):

- Travel times and vehicle operating costs.
- Accidents.
- Emissions (CO, NO_x, PM₁₀, VOC, with cold-start component).
- Energy consumption.
- Noise.

Figure 4 depicts the internal structure of the STEAM model (7).

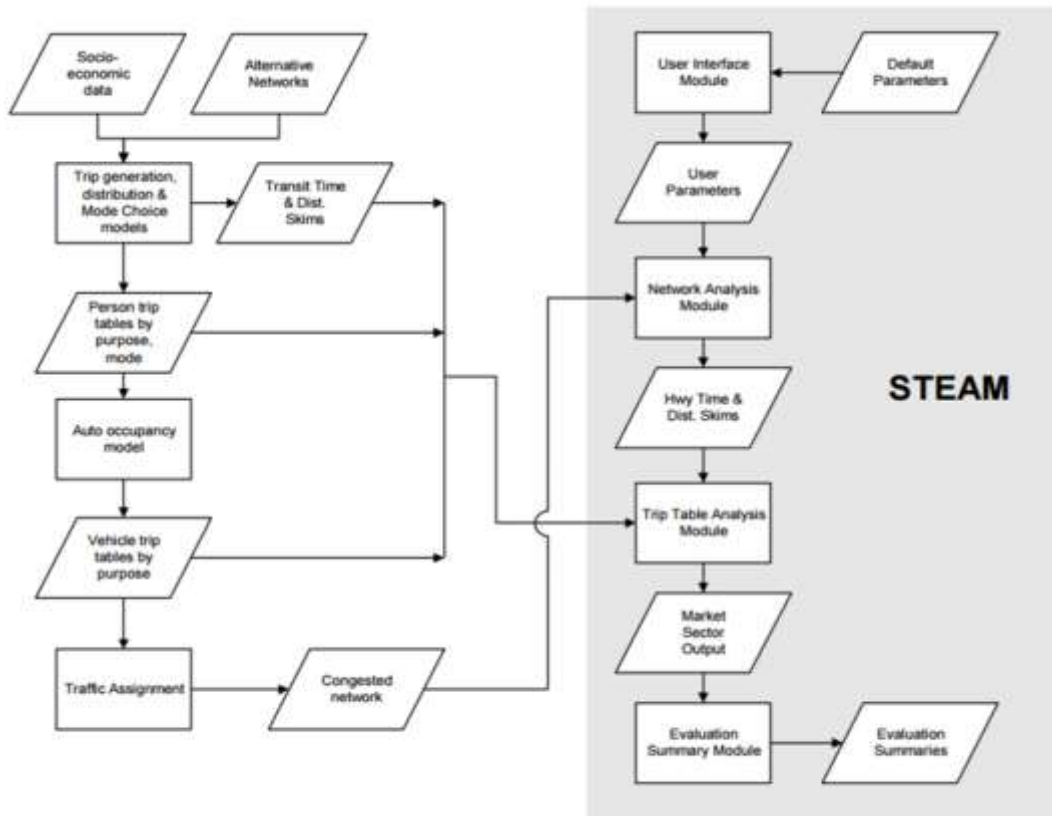


Figure 4. STEAM Model Internal Structure.

Cost categories in STEAM are considered infrastructure investments and operating costs (8). Economic performance measures are net present worth and benefit-cost ratio for each alternative in question (8). Results are presented as net present values or benefit-cost ratios.

STEAM 2.02, is the latest version of STEAM, which allows users to assess mobility and safety benefits by user-defined districts. “The district-level reporting feature allows users to compare the impacts of transportation investments to resident trip-makers across aggregations of zones. The accessibility feature produces estimates of employment opportunities within a user-defined travel-time threshold of a district across a base and improvement scenario. The district reporting and accessibility features are useful new tools for gauging the social impacts of transportation investments” (9).

Input requirements factored in STEAM are illustrated in Table 1, and quantitative impacts factored in STEAM are illustrated in Table 2 (6).

Table 1. STEAM Input Requirements.

Input Requirements	Default Provided?
Highway network files produced by traffic assignment procedures (for Base Case and each alternative to be analyzed)	No
Trip tables indicating the number of trips between each pair of analysis zones	No
Zone-to-zone transit travel times (if transit improvements are included in the system alternatives to be analyzed)	No
Population and employment by zone (if accessibility measures are to be produced)	No
Transit service changes (system wide vehicle miles, vehicle hours, and peak vehicles)	No
Capital costs	No
Maintenance costs	No
Residual values	No
Discount rate to account for time value of money	Yes
Cost and tax per gallon of fuel	Yes
Emission rates (by speed range) and emission costs for HC, CO, NO _x , and PM ₁₀	Yes
Accident rates (by highway class) and unit costs for fatal, injury, and property damage accidents	Yes
Fuel consumption rates by speed range	Yes
Non-fuel vehicle operating cost per mile	Yes
Value of in-vehicle and out-of-vehicle travel time	Yes
Noise cost per vehicle mile by facility type	Yes
Transit agency costs (per vehicle mile, vehicle hour, and peak vehicle)	Yes
Other external costs per vehicle mile and non-mileage-based external cost (e.g., construction period impacts)	No
Highway network files produced by traffic assignment procedures (for Base Case and each alternative to be analyzed)	No

Table 2. STEAM Impact Types

Impact Types	Description
Agency Costs	Annualizes agency costs for comparison to analysis year benefits
Congestion/Mobility Impacts	<p>Post-processes traffic assignment volumes generated from conventional four-step planning models to get more accurate highway travel speeds, especially under congested conditions.</p> <p>Accounts for delays due to incidents (using data on the frequency, severity, and duration of incidents), peak spreading that occurs when facilities become more congested, and day-to-day variations in traffic</p> <p>Outputs include person hours of in-vehicle and out-of-vehicle time</p>
Safety Impacts	<p>Applies accident rates by facility type.</p> <p>Outputs include:</p> <ul style="list-style-type: none">• Fatal accidents• Injury accidents• Property damage only accidents• Accident costs
Vehicle Operating Cost Impacts	<p>Applies fuel consumption rates (gallons per mile) as a function of speed and vehicle type.</p> <p>Applies unit costs for non-fuel operating costs as a function of vehicle type.</p>
Environmental Impacts	<p>Calculates emissions for autos, trucks, and carpools as the sum of: 1) mileage-based emissions on the highway system (calculated under the assumption that vehicles are already warmed up); and 2) added emissions due to cold starts.</p> <p>Mileage-based emissions are calculated as a function of speed.</p> <p>Calculates noise costs based on noise damage rates by type of vehicle and facility.</p> <p>Outputs include:</p> <ul style="list-style-type: none">• HC, CO, NOx, and PM10 emissions and costs• CO2 emissions and costs• Noise costs
Other	<p>Calculates accessibility measures such as the number of jobs within x minutes of a specified area</p> <p>Calculates revenue transfers associated with changes in tolls and fares.</p>

Case Study #3: Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS)

Initially developed by the FHWA and continually maintained by Cambridge Systematics, Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS) is a sketch-planning tool designed to estimate and predict costs and benefits of ITS investments (10, 11). IDAS is intended for the screening and prioritization of ITS alternatives for transportation practitioner use (10, 11).

The tool evaluation begins with inputs from travel demand model outputs. IDAS uses the information to calculate the standard transportation measures for both the base case (control alternative) and the proposed plan (ITS alternative). The difference in the calculations represents the change in the network as a result of the ITS components. In turn, these changes are used to calculate the benefits (and the costs) associated with the proposed plan (10). Figure 5 depicts the internal structure of IDAS (10).

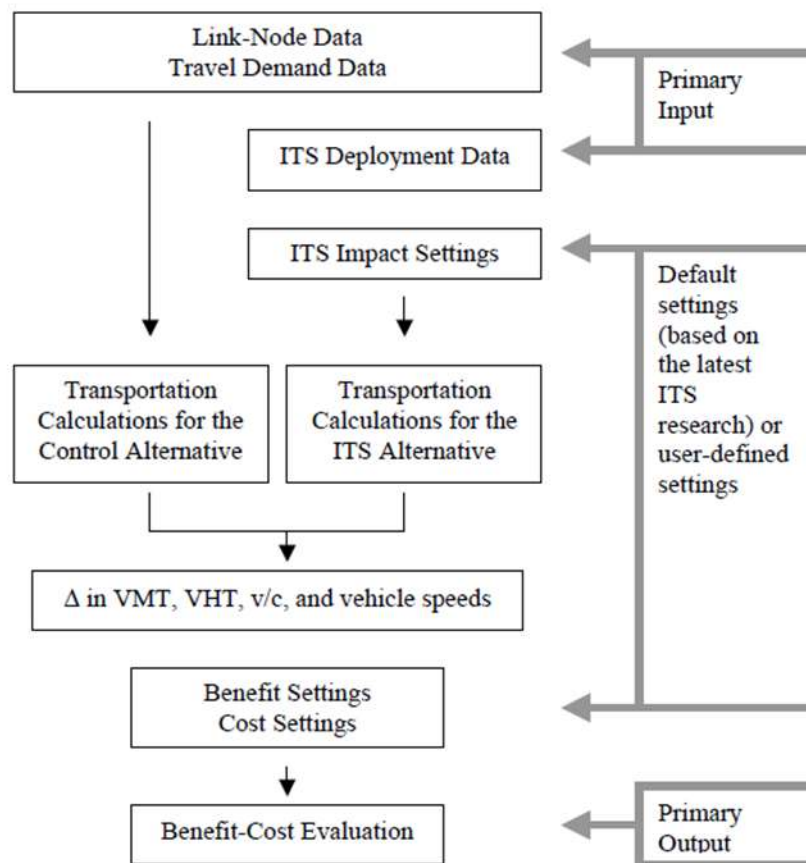


Figure 5. IDAS Internal Structure.

According to the user manual, “IDAS operates as a post-processor to travel demand models, enabling the user to import data from a travel demand model into the IDAS software to recreate the transportation network under evaluation. IDAS provides the opportunity to build different network alternatives by enabling users to choose from a menu of ITS and operations components and then deploy the selected network components. As the user chooses various components, IDAS maintains a database of the impacts and costs of the components based on national data. After the components are selected, users can program IDAS to perform an internal network assignment and mode choice analysis to estimate the changes in modal, route, and temporal decisions of travelers resulting from ITS and operations technologies. The software generates reports to show incremental change in performance measures and annual benefit-cost ratios for the selected investments” (11).

Performance measures used in the IDAS model are placed in two categories (7):

- Standard transportation measures for the base case or “control alternative” including vehicle miles of travel (VMT), vehicle hours of travel (VHT), volume-capacity (v/c) ratios, and vehicle speeds.
- Standard transportation measures for the proposed plan or “ITS alternative” with consideration of the impact from the ITS deployment.

The following system-wide performance measures are estimated by IDAS, which are segmented by market sector, facility type, or district/user defined area (11):

- Mobility or travel time (recurring delay).
- Travel time reliability (nonrecurring delay).
- Crashes (fatalities, injuries, property damage).
- Emissions (hydrocarbons, carbon monoxide, NO_x, PM₁₀).
- Fuel use.
- Agency efficiency and productivity.
- Capital, operating, and maintenance costs.
- Benefit-cost ratios.

IDAS has been successfully implemented across the country and around the world, and is being used by transportation practitioners to (11):

- Analyze ITS and operations alternatives for long-range plans.
- Evaluate existing and new ITS and operations systems.
- Perform major investment, corridor, and freight/goods movement studies.

- Analyze congestion management systems, work zones, and air quality impacts of projects.

Key characteristics of IDAS include:

- The scope allows the tool to evaluate the costs and benefits of various ITS components only.
- The tool can integrate with the leading travel demand models.
- The capability to use readily available data.
- The ability to be updated progressively at a cost-effective price.

Impacts factored in the IDAS mode are shown in Table 3 (10).

Table 3. Impacts Evaluated in IDAS.

ITS Goal	Impacts	Determined by the change in
Efficiency and Capacity	In-Vehicle Travel Time	VHT
	Out-Vehicle Travel Time	VHT
Mobility	User Mobility	VHT
	Travel Time Reliability	VMT, v/c, ratio
Safety	Internal Accident Costs (paid by the traveler)	VMT, v/c, ratio
	External Accident Costs (paid by society as a whole)	VMT, v/c, ratio
Energy and Environmental Costs	Fuel Costs	VMT, vehicle speed
	Vehicle Emissions (HC/ROG, NOx, CO, PM10, CO2, Global Warming)	VMT, vehicle speed
	Noise Impact	VMT

Case Study #4: Highway Economic Requirements System – State Version (HER-ST)

The Highway Economic Requirements System – State Version (HERS-ST) is a benefit-cost analysis tool developed by the FHWA. The goal of HER-ST is to estimate levels of investment to achieve the performance of the highway system and explore the relationship between levels of investment and performance of the highway system. HERS-ST is a direct extension of the national-level model, designed for state and regional transportation agencies to maximize the economic benefits relative to costs (2,12).

The function of the HERS model is to estimate the project/program cost and benefits. “HERS-ST uses current highway system information, including deficiencies, obtained from FHWA’s Highway Performance Monitoring System (HPMS). The model generates a set of standard

highway system improvements, to be augmented by additional user-specified improvements. It searches for the best combination of improvements for which economic benefits exceed costs. Up to six different investment alternatives are considered for each highway segment by combining possible improvements to pavement, width, and alignment. Options not considered include: the construction of new highway segments, improvement to non-highway modes, and improvements to major bridges and tunnels” (13). Figure 6 is a depiction of the internal structure of the HERS-ST model (12).

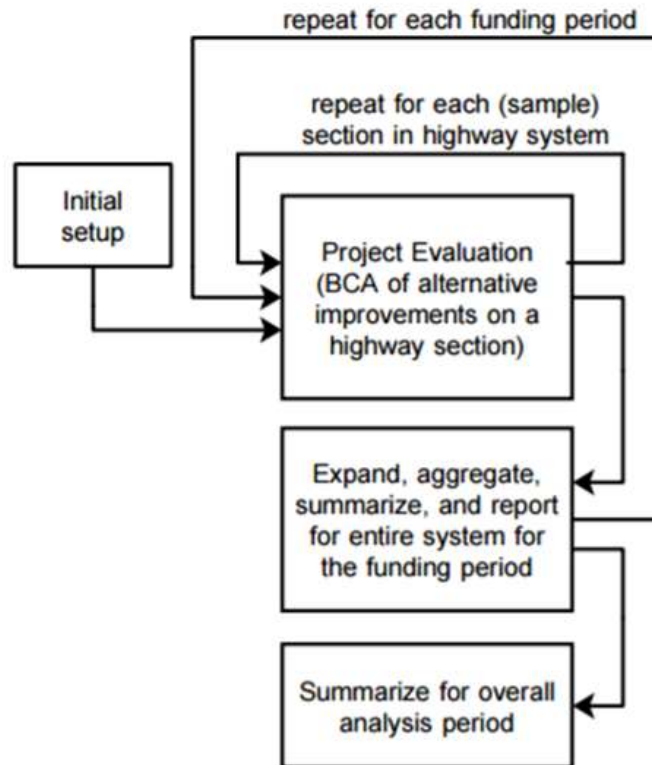


Figure 6. HERS-ST Model Internal Structure.

The scope of the model evaluation process encompasses three major steps as shown in Figure 7 (12).

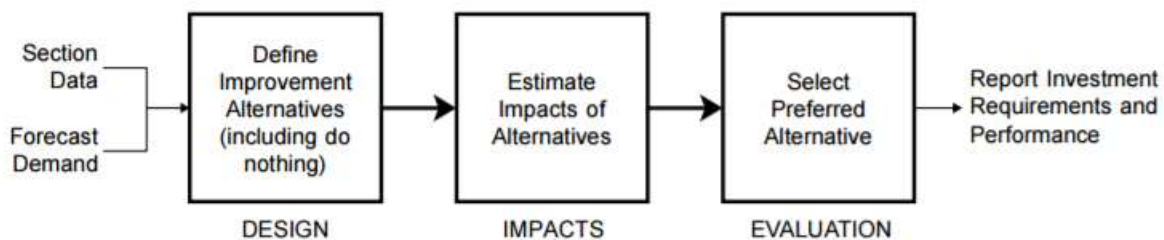


Figure 7. HERS-ST Model Evaluation Process.

According to the Transportation Benefit-Cost Analysis website, HERS-ST “selects economically desirable improvements for nine major functional classes of highways, excluding local facilities and minor rural collectors. Candidate improvement projects are identified for each segment of a highway system serving a state or region. Existing and forecasted (future) conditions are described, with and without the candidate improvements, and the optimum combination of improvements are determined” (13).

The benefit and cost categories considered by HERS-ST include (13):

- Benefit Categories:
 - Changes in user travel times.
 - Changes in vehicle operating costs (fuel, oil, tires, maintenance, depreciation).
 - Changes in collisions.
 - Changes in emissions (combined costs of CO, NOX, PM10, VOC, SOX, and road dust).
 - Changes in agency costs for highway maintenance and operations.
 - Changes in highway residual values.
- Cost Categories:
 - Initial right-of-way acquisition.
 - Construction costs.

Other quantitative impacts considered in the HERS-ST model include (13):

- Measures of congestion (peak volume-capacity ratio).
- Speed by segment and averaged by functional class.
- Delays.
- Pavement condition (PSR and IRI) by segment and averaged by functional class.
- Selected geometric improvements for each highway segment.
- Deficiency ratings, before and after selected improvements.
- Collision rates, before and after selected improvements.

Key characteristics of the HERS-ST model include:

- Scope to evaluate the costs and benefits of various highway capital improvement projects.
- Compatibility to integrate the model with the graphical information system (GIS).
- Capability to use the model as a Microsoft Window-based application.

Conclusion of Case Studies

The case studies for the sketch-planning tools found that the tools appear to use a range of techniques and aggregated data to perform analysis for all phases of the transportation planning process. Sketch-planning tools are typically “the simplest and least costly of the traffic analysis techniques, but limited in scope, analytical robustness, and presentation capabilities” (14). Sketch-planning tools produce general order-of-magnitude estimates for travel demand and/or travel speeds in response to various transportation strategies (14). These tools are commonly used to estimate the benefits of projects with certain built-in components, such as Active Traffic Management, Congestion Management Process (CMP), Incident Management, Intelligent Transportation Systems (ITS), Transportation Control Measures (TCM), and Transportation Demand Management (TDM). While all four tools provide some manner of estimation, most are still complex in order to provide a significant amount of detail. A person with little knowledge of the transportation planning process may still find difficulty in estimating a project’s benefit. Additionally, none of the sketch planning tools are capable of examining the benefits of the full suite of congestion mitigation strategies or of multiple strategies simultaneously.

FIXiT 1.0 Tool

In 2013, TTI researchers developed the Future Improvement Examination Technique (FIXiT) 1.0 tool as part of the Mobility Investment Priorities (MIP) project in order to estimate the effect of a wide range of congestion benefits from proposed projects, programs, and, plans along congested urban corridors. What was unique about FIXiT was its ability to integrate adjacent and parallel corridor impacts from proposed projects, with the assumption that a project does not simply impact the small segment where it is constructed.

FIXiT focuses on congestion relief during peak hours—arguably the most critical point when seeking to improve congestion conditions. In the MIP project, the tool used a four-step analysis process to analyze projects in Austin, Houston, and San Antonio. This process included:

- Input data – Inputted information from the *Texas 100 Most Congested Sections List* and Road-Highway Inventory (RHiNo) databases into the FIXiT model with a selected proposed improvement strategy from the available list (15,16,17).
- Perform Interim Calculations – Input data are converted and used in background calculations to provide a consistent basis for comparison of before and after conditions.
- Estimate Congestion Effects of Proposed Project – Percent change in peak period speed applied to actual base year conditions from the Texas 100 dataset to estimate after conditions.
- Summarize Network Effects – The previous steps are repeated for parallel, perpendicular, and adjacent roadway sections of the modified road that will be affected by the improvement to calculate the network effect.

During the process, inputs included the road directly affected by the project and other segments in the surrounding network. Table 4 shows estimated effects of five projects included in the original MIP analysis, including a reduction in daily peak period delay of between 500,000 and 1.6 million person-hours. This result represented an improvement of between 21 and 35 percent. The peak direction speeds for periods experiencing the most congestion in each corridor were lower than the two-way full peak period average speeds listed in Table 4. The congestion benefits were primarily seen on the improvement segments with lower benefits on the surrounding road networks.

The delay savings and associated fuel savings had a value of more than \$30 billion over the project lifetime, a return of approximately \$4.50 for each dollar of project construction and maintenance cost (3).

Table 4. Congestion Improvement Estimates for Five Large Projects

City	Route	2013 Statewide Congestion Rank	Current Peak Period Speed	Proposed Peak Period Speed	Current Peak Period Delay	Proposed Peak Period Delay	Percent Change in Peak Period Delay
Austin	IH 35 North	1	52	56	4,903,000	3,260,000	34%
Austin	Loop 1 South	27	49	52	2,531,000	2,045,000	21%
Houston	IH 45 North	10	52	55	6,351,000	4,837,000	24%
San Antonio	IH 35 North	37, 38	53	58	3,191,000	2,212,000	31%
Houston	US 290	18	51	55	4,528,000	2,919,000	35%

The FIXiT tool provided a good starting place to calculate the reduction benefits, but more detailed computer modeling was proposed for a full analysis of any mitigation strategy.

Limitations of FIXiT 1.0

This first version of the tool had several limitations that made its use cumbersome. First, the tool fundamentally classified the congestion benefits in terms of percent lane equivalents—how many traffic lanes would have to be built in order to achieve the same impact. Benefits were estimated based on how many cars they could take off the road, which could then be translated into a delay reduction. While this was convenient for some basic congestion mitigation strategies, it was incredibly difficult for non-traditional strategies, such as TDM, ITS, multimodal techniques, and others to be converted into this metric. Additionally, researchers had great difficulty justifying these benefit numbers based on observations from previous studies of the congestion strategy.

This fundamental approach in itself created a second limitation of the tool: it made the algorithms and assumptions in the tool incredibly complex. While the tool pursued a certain level

of accuracy, the approach ballooned into 17 sub-processes, each requiring its own set of assumptions.

Third, one aspect FIXiT could not do well was integrate multiple strategies into one corridor at the same time. For example, if planners wanted to see the combined benefits of adding ramp metering and acceleration lanes, the tool could only provide individual benefits for each strategy, but in this example, there is clearly a diminishing return and marginal benefit by combining these two strategies into one project. Current best practice for congestion mitigation seeks to find several lower-cost solutions that could provide some benefit, so being able to perform this task was critical.

FIXiT 2.0

Because of the previous limitations of the original FIXiT tool, researchers desired to update the tool to provide a simpler, more usable tool that could address the primary limitations and eventually be used at a local level without significant transportation modeling expertise.

Initial efforts by researchers began by attempting to reconfigure the existing model to add a layer of complexity that would address the limitations. However, researchers quickly scrapped this effort because the added complexity made the tool unusable. Researchers realized that conceptually, since delay calculations were already being made for more than 1,800 roadway segments through TxDOT's *Texas 100 Most Congested Roadways* effort, this portion of the FIXiT tool could be completely eliminated. The use of the benefit common denominator of equivalent lanes was also called into question. Why convert benefits away from this when several before/after studies report congestion benefits in terms of delay reduction or a similar metric?

These conceptual realizations shifted the tool's conceptual base towards a simpler idea: determine the delay reduction for each strategy and multiply that by the known delay on a roadway. This concept dramatically simplifies the tool, enables multiple strategies to be calculated at once, and allows the tool's results to be based on observed data for each congestion mitigation strategy.

While this new approach may reduce the overall accuracy to some degree, the estimate ranges provided would still be suitable as a sketch-planning tool and would serve as an extremely conservative baseline for benefit estimation.

The update, then, is composed of two distinct parts: 1) developing a master table of recommended delay reduction benefits for each congestion mitigation strategy based on observed information, and 2) simplifying the tool's algorithms to integrate this new methodology.

Congestion Mitigation Strategy Benefits Table

To fill the gaps of the previous FIXiT model, researchers created the “Recommended Delay Reduction Benefits for Congestion Mitigation Strategies” table based on FIXiT 1.0’s original benefits table to serve as the foundation for the FIXiT 2.0 model. Appendix A contains the complete table now used in the updated model.

Researchers developed this table after a thorough literature search on the recorded benefits of each congestion mitigation strategies identified through the MIP process. The research effort included effects on how the strategy impacts congestion, safety, parking, and public transportation and general knowledge of transportation issues. These measures were identified as contributing the most value to a transportation network system, local or state agency, and the public. It is important to note that not every strategy impacted an area according to every measure used in the table. This table combines real measured impacts with expert judgement to set the foundation to identify a percent delay recommendation used to calculate the overall benefit by the tool. Note that researchers avoided using modeled benefit information.

Contents of the table include:

- Area.
- Congestion Strategy.
- Congestion Strategy Sub-category.
- Geographical Impact.
- Impact Findings.
- Delay Measure.
- Percent Recommendation.

Area

Area of transportation represents the target subject of the congestion strategy, which includes congestion, capacity, finance, policy, technology, or freight. Certain strategies may have affects that cross over several subject areas, so it is important to note that strategies are not limited to affecting only one area of transportation.

Congestion Mitigation Strategy

Congestion mitigation strategies include traffic operations, travel options, system capacity techniques, and alternative modes of transportation, which will serve a prominent role in Texas’ future as congestion continues to worsen. Each strategy will serve a certain role in the network, such as improving efficiency by clearing collisions or improving signal coordination; reducing demand on the system by offering alternatives to driving; or modifying the road network system to use existing road space more efficiently. These strategies are not meant to serve as a single solution for all of an area’s congestion problems, but are rather meant to be part of a long-term solution to enhance the livability of an area.

Congestion Strategy Sub-Category

The congestion strategy sub-category serves to group strategies based on the area of transportation it influences. The table contains nine sub-categories:

- Active traffic management.
- Additional capacity.
- Bicycle & pedestrian facilities.
- Construction improvements.
- Pricing strategies.
- System modification.
- Traffic management.
- Transit.
- Travel options.

Note that as additional strategies and subcategories are added to TTI's congestion mitigation webpage, <https://tti.tamu.edu/policy/congestion/how-to-fix-congestion/>, these categories may change. For example, as information on specific land use strategies becomes available, the table will be updated to include that category.

Geographical Impact

The impact category is a unique feature incorporated into the updated tool, which designates a geographical area the congestion strategy will influence. By designating a geographical area for a congestion strategy, users of the tool will have the ability to prioritize which projects will contribute to the greatest effect on a certain location. Through this, planners and decision makers can ensure sound financial stewardship in the early stages of the project selection process, leading to increased public trust. The ability to analyze projects based on their geographical effect on an area is an improvement from the past model as only spot-specific road analysis was previously achievable. The spot-specific road analysis functionality was added as an improvement in later models found in the literature review. With this improvement, cities and MPOs will have the ability to use the tool as a means of strategic planning to set goals, prioritize projects, and identify a vision for the future.

Impact Findings

The impact findings are measured impacts found during the literature search. These are known measured effects that an area that has implemented a specific strategy have experienced. The impacts were grouped into broad categories below, but each strategy may not influence every category identified.

- Congestion.
- Safety.
- Knowledge.
- Parking.
- Public Transportation.

As additional before/after studies are released on various projects throughout Texas, the nation, and globally, researchers will integrate those findings into the table, adjusting the benefits ranges and delay reduction numbers accordingly.

Delay Measure

Delay was selected as a measure because an economic value for an entire transportation system network can typically be easily calculated and leverage other data sources. This is key for planning agencies because when identifying funding and prioritizing projects, they must select projects that will have the greatest impact on the entire network system and not just a single mode. Since automobile transportation is the dominant mode, any improvement in congestion presumably will be reflected in a reduction of auto congestion. Therefore, multimodal and other non-auto strategies will have a delay reduction number. This addresses a common critique against using delay as a measure in that it uses an already-established measure to include and promote non-auto modes and congestion mitigation strategies.

The table categorizes delay into regional and local levels. The regional level encompasses the whole transportation network system while the local level is at a scale, which can be used at both the spot and corridor level. Delays were funneled further into recurring and non-recurring delay. Recurring delay is attributed to a consistent level of peak travel that commuters expected daily and typically encounter. Non-recurring delay is a less reliable number, as it represents events that cannot typically be predicted, such as crashes, weather events, or other occurrences that cause congestion.

Percent Recommendations

Recommended percent benefits were determined through impact findings from the literature search and expert professional judgement based on areas with observed calculated before and after studies from the congestion mitigation strategies.

Updated Methodology

FIXiT 2.0 will use a variety of data sources to calculate a magnitude value of reduction benefits. The updated FIXiT tool was developed with knowledge gained from the literature review. Many aspects from previous working models were selected to improve the current FIXiT model. Figure 8 represents an overview of the 4-step process used in the revised FIXiT tool.



Figure 8. Calculation Process for FIXiT 2.0.

The following sections provide a description of the updated tool’s methodology using a simple excel spreadsheet to perform the calculations.

Section A: Input Data

Section A describes the first steps of the data input process for FIXiT.

Step A1: Calculate Delay by Segment.

Peak Period Annual Hours of Delay (typically between 6 and 9 a.m. and 4 and 7 p.m.), Off-Peak Annual Hours of Delay, and Weekend Annual Hours of Delay for individual segment are obtained from TX100 2015 Dataset. Detailed information for the data includes:

- **Peak Period Annual Hours of Delay (person-hours)** = Peak Period Annual Hours of Delay (person-hours) [Source: TX100 2015].
- **Non-Peak Period Annual Hours of Delay (person-hours)** = Off-Peak Annual Hours of Delay (person-hours) [Source: TX100 2015] + Weekend Annual Hours of Delay (person-hours) [Source: TX100 2015].
- **Total Annual Hours of Delay (person-hours)** = **Peak Period Annual Hours of Delay (person-hours)** + **Non-Peak Period Annual Hours of Delay (person-hours)**.

Step A2: Calculate Delay by Urban Area.

Step A2 selects the Peak Period Annual Hours of Delay (person-hours), Off-Peak Annual Hours of Delay (person-hours), and Weekend Annual Hours of Delay (person-hours) for individual segment from TX100 2015 Dataset. Like the previous step, individual segments are grouped by corresponding Urban Areas. Three types of Annual Hours of Delay (person-hours) are added up to determine the individual Urban Area delay.

- **Peak Period Annual Hours of Delay (person-hours)** = Peak Period Annual Hours of Delay (person-hours)_{Segment 1} + ... + Peak Period Annual Hours of Delay (person-hours)_{Segment N} [Source: TX100 2015].
- **Non-Peak Period Annual Hours of Delay (person-hours)** = {Off-Peak Annual Hours of Delay (person-hours)_{Segment 1} + ... + Off-Peak Annual Hours of Delay (person-hours)_{Segment N}} [Source: TX100 2015] + {Weekend Annual Hours of Delay (person-hours)_{Segment 1} + ... + Weekend Annual Hours of Delay (person-hours)_{Segment N}} [Source: TX100 2015].
- **Total Annual Hours of Delay (person-hours)** = **Peak Period Annual Hours of Delay (person-hours)** + **Non-Peak Period Annual Hours of Delay (person-hours)**.

Step A3: Load Delay by Segment and Delay by Urban Area as Input Data.

Three types of Annual Hours of Delay (person-hours) are loaded into “Delay by Segment” and “Delay by Urban Area” tabs of the FIXiT spreadsheet. The input data in the FIXiT spreadsheet

will correspond to the TX100 2015 dataset. An important feature of the tool is that all FIXiT input and output statistics are presented in annual units.

Step A4: Choose Segment Name or Urban Area Name to be Analyzed.

The FIXiT spreadsheet is programmed with dropdown menus in the “Delay by Segment” and “Delay by Urban Area” tabs to include all segments and urban areas from the TX100 2015 dataset. Once the segment or urban area name is selected, the spreadsheet automatically retrieves the three types of Annual Hours of Delay (person-hours) data. Step A4 is designed to reduce the amount of data transferred by the user, enhancing efficiency and improving accuracy.

Section B: Select Strategies

Section B describes the steps for the selection of the congestion mitigation strategies.

Step B1: Select Congestion Mitigation Strategies to be Applied.

The dropdown menu draws from the “Strategy by Segment” and “Strategy by Urban Area” tabs in the FIXiT spreadsheet and provides a choice of 41 congestion mitigation strategies for segment improvement and 77 congestion mitigation strategies for urban area improvement. Congestion mitigation strategies for segment improvement can be applied only once to the spot and corridor level while congestion mitigation strategies for urban area improvement can be applied to all five levels (spot, corridor, local, regional, and state).

Each individual congestion mitigation strategy identified in the “Strategy” tab has nine delay reduction benefit values with six values for segments and three values for urban areas, as seen from the following:

Segment Delay Reduction Benefit Values

- Total Delay Low Scenario
- Total Delay High Scenario
- Recurring Delay Low Scenario
- Recurring Delay High Scenario
- Non-recurring Delay Low Scenario
- Non-recurring Delay High Scenario

Urban Delay Reduction Benefit Values

- Total Delay
- Recurring Delay
- Non-recurring Delay

FIXiT has a default choice for three congestion mitigation strategies to be applied to the segment or urban area. For Strategy #2 and Strategy #3, the user has the option to select None, for which a strategy will not be selected to the segment or urban area. For the first congestion mitigation strategy, the user will not have the option to select “None.” Once the congestion mitigation strategy is selected, the spreadsheet will retrieve the corresponding delay reduction benefit values, designed to reduce the amount of data transferred by the user, enhancing efficiency and improving accuracy.

Step B2: Select Depreciation Values to be Applied.

Researchers recognized early that applying multiple strategies at once will have a certain level of diminishing returns for every additional strategy applied. Researchers built in a feature to account for this. FIXiT has a default choice of seven depreciation values (0 percent, 25 percent, 33 percent, 50 percent, 66 percent, 75 percent, 100 percent) to be applied to the second and third congestion mitigation strategies. However, when the user selects “None” from the second and third dropdown list for individual segments, the default depreciation value is set as 100 percent, while the default depreciation value for an individual urban area is 0 percent. Under circumstances stated above, both default values cannot be altered by the user. It is important that the user select their own depreciation values because the spreadsheet will not automatically retrieve the depreciation values for selected strategies. The depreciation values should be chosen by the user based on their best professional judgements of what strategy will have the biggest impact, and if strategies will have mutually exclusive benefits or some combination of combined benefit.

Section C: Perform Calculations

Section C describes the process of calculating delay reduction benefits through a series of equations for both segment and urban area.

Step C1: Calculate Delay Reduction Benefits by Segment.

Step C2: Calculate Delay Reduction Benefits by Urban Area.

Delay reduction benefits are calculated at both the segment and urban area level. Default assumption is set as 50 percent reduction in delay for both recurring and non-recurring delay. Delay reduction benefit values are applied to the current values to estimate the benefits after implementing congestion mitigation strategies to the certain study area. See Appendix B: FIXiT Calculation Equations for more equation details for section C.

Section D: Report Benefits

Step D1: Select Time of Day.

Three time periods are offered: Peak Period Annual Hours of Delay (person-hours), Non-Peak Period Annual Hours of Delay (person-hours) and Total Annual Hours of Delay (person-hours).

Step D2: Select Delay Type.

Three delay types are offered: Total Delay Reduction, Recurring Delay Reduction, and Non-Recurring Reduction.

Step D3: Select Scenario.

The user can choose from Low Scenario and High Scenario. Low Scenario assumes the lowest congestion mitigation benefit provided to an area, and High Scenario assumes the highest benefit for an area.

Step D4: Report Benefits.

FIXiT automatically reports the delay reduction benefits values after each selection.

Conclusion

As the state continues to grow and roadway infrastructure continues to experience strain and pressure from this growth, finding the appropriate mix of congestion mitigation and mobility strategies to provide a holistic and robust transportation network will be crucial. Finding ways to spend limited state resources wisely in order to obtain the biggest benefit will continue to be a priority at every level of the planning process, but ensuring early on that rough cost and benefit estimates meet expectations will be crucial.

This update to the FIXiT tool will allow a sketch-planning process that is responsive to the needs of the State Legislature as well as regional partners and planning officials. Through the updated process, FIXiT 2.0 can report unbiased benefits one or a package of congestion mitigation strategies may provide to an area or corridor.

Users of the results from the tool should remember that outputs are ranges that are still estimates based on comparable findings. During the update process, researchers designed the tool to provide conservative estimates where possible to understate the potential benefit of a strategy in order to manage potential expectations from a project. This is important to keep in mind during the project selection process.

The results of the tool should not be used as a final factor in determining project prioritization, but should be used as an early screening tool in conjunction with a series of factors when allocating funding and prioritizing projects for an area.

In the future, researchers would like to continue to develop this tool and make it widely accessible to state and regional planners and staff with some level of automated control with an intuitive interface. The benefits table will continue to be updated as new information becomes available.

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**Appendix A:
Recommended Delay Reduction Benefits for Congestion
Mitigation Strategies Table**



Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
Acceleration/Deceleration Lanes (Speed Change Lane) (1)	Congestion	System Modification	Spot	Congestion: -68 to -82% Average Speed: +9%	Region	-7%
					Region Recurring	-10%
					Region Non-Recurring	-5%
					Local	-10 to -15%
					Local Recurring	-15 to -20%
Local Non-Recurring	5 to -10%					
Access Management (2)	Congestion	System Modification	Corridor	Crashes: -15 to -57%	Region	-10%
					Region Recurring	-20%
					Local	-5 to -20%
					Local Non-Recurring	-10 to -30%
Bottleneck Removal (3)	Congestion	System Modification	Corridor Spot	Crashes: -35%	Region	-15%
					Region Recurring	-10%
					Region Non-Recurring	-20%
					Local	-12 to -25%
					Local Recurring	-15 to -20%
Local Non-Recurring	-10 to -30%					
Freight Shuttle System (4)	Freight	Additional Capacity	Regional	Percent Target of Total Freight Market: 70%	Region	-2%
					Region Recurring	-2%
					Region Non-Recurring	-2%
					Local	-5 to -15%
					Local Recurring	-5 to -10%
Local Non-Recurring	-5 to -20%					
Grade Separation (5)	Congestion	Additional Capacity	Spot	Crashes: -28 to -57% Fuel Consumption: -3.5 to -12.5%	Region	-2%
					Region Recurring	-2%
					Region Non-Recurring	-2%
					Local	-5 to -15%
					Local Recurring	-5 to -10%
Local Non-Recurring	-5 to -20%					
Managed HOT/HOV Lanes (6)	Capacity	System Modification	Corridor	Speed of HOT/HOV Lanes: +7 to +8% Speed of Adjacent Toll-Free Lanes: +10% Volume of HOT/HOV Lanes: +1 to +7% Volume of Adjacent Toll-Free Lanes: +3 to +5% *Total Delay: -22% *Vehicle Hours Traveled: -7.5% *Travel Time: -16%	Region	-10%
					Region Recurring	-10%
					Region Non-Recurring	-10%
					Local	-12 to -22%
					Local Recurring	-10 to -15%
					Local Non-Recurring	-15 to -30%
Adding New Lanes or Roads (7)	Congestion Finance	Additional Capacity	Corridor	Crashes: -25 to -50% Capacity: +25%	Region	-12%
					Region Recurring	-20%
					Region Non-Recurring	-5%
					Local	-10 to -30%
					Local Recurring	-10 to -40%
Local Non-Recurring	-10 to -20%					
Adding New Toll Roads (8,9)	Capacity Congestion Finance	Additional Capacity	Corridor	Travel Time at Choke Points: +3 to +75% Travel Time on Major Arterials: +4 to +69% Travel Time Compared to Local Roads: -22 minutes	Region	-12%
					Region Recurring	-20%
					Region Non-Recurring	-5%
					Local	-10 to -30%
					Local Recurring	-10 to -40%
Local Non-Recurring	-10 to -20%					

Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
Ramp Configuration (10)	Congestion	System Modification	Corridor Spot	Travel Time: -7 to 91% Benefit-Cost Ratio: 9:1 Crashes: -31 to -41%	Region	-2%
					Region Recurring	-2%
					Local	-5 to -10%
					Local Recurring	-10 to -20%
Temporary Shoulder Use (11)	Technology	Active Traffic Management	Corridor	Travel Time: -27 to -34% Capacity: +7 to +22% Volume: +7 to +20% Congestion: -30%	Region	-5%
					Region Recurring	-10%
					Local	-5 to -10%
					Local Recurring	-10 to -20%
Bicycle Lanes (12)	Congestion	Bicycle & Pedestrian Facilities	Local	Traffic Congestion: -2 to -3% Bicycle Volume: +80 to +180% Bicycle Commuting: +0.11% Mode Change: +1.05 to +1.72% Bicycle/Car Related Crashes: -29%	Region	-1%
					Region Recurring	-2%
					Local	-2%
					Local Recurring	-4%
Bicycle-Pedestrian Education and Encouragement (13,14,15)	Congestion	Bicycle & Pedestrian Facilities	Regional	Drive-Along Trips: -7 to -10.4% Bicycle Volume: +12.9 to +45% Traffic-Related Fatalities: 58%	Region	-0.5%
					Region Recurring	-1%
					Local	-0.5%
					Local Recurring	-1%
Bike Sharing (14)	Congestion	Bicycle & Pedestrian Facilities	Local	Congestion: -2 to -3%	Region	-1%
					Region Recurring	-2%
					Local	-2%
					Local Recurring	-4%
Cycle Tracks (16)	Congestion	Bicycle & Pedestrian Facilities	Local	Crashes with injuries: -17% Bicycle Ridership: +21 to +171%	Region	-1%
					Region Recurring	-2%
					Local	-2%
					Local Recurring	-4%
Multimodal Transportation Center (Corridors) (17)	Congestion	System Modification	Corridor	Mode Shift: + 2 to +52%	Region	-2%
					Region Recurring	-5%
					Local	-0.5%
					Local Recurring	-1%
Pedestrian Connections (18)	Congestion	Bicycle & Pedestrian Facilities	Local	Walking Traffic: +15.8% Pedestrian Fatalities: -20% Pedestrian Crashes: -46%	Region	-0.5%
					Region Recurring	-1%
					Local	-0.5%
					Local Recurring	-1%
Active Traffic Management (19)	Technology	Active Traffic Management	Regional	Capacity: +22% Crashes and Secondary Incidents: -30 to -50%	Region	-10%
					Region Recurring	-10%
					Region Non-Recurring	-10%
					Local	-10 to -15%
					Local Recurring	-10 to -25%
					Local Non-Recurring	-10 to -20%
Diverging Diamond Intersection (20)	Congestion	System Modification	Spot	Vehicle Stops: -38% Crashes: -26 to -46% Public Perception of Safety: +87%	Region	-10%
					Region Recurring	-10%
					Region Non-Recurring	-10%
					Local	-7 to -15%
					Local Recurring	-5 to -10%

Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
					Local Non-Recurring	-10 to -20%
Dynamic Rerouting (21)	Technology	Active Traffic Management	Regional	Overall System Performance: +5% Divert Through-Travelers: +27 to +40% Traffic Volume: -10% Driver Compliance: +8 to +10%	Region	-3%
					Region Recurring	-5%
					Local	-5 to -10%
					Local Recurring	-5 to -10%
Dynamic Truck Restrictions (22)	Technology Freight	Active Traffic Management	Corridor	Capacity: +3%	Region	-1%
					Region Recurring	-3%
					Local	-2 to -4%
					Local Recurring	-3 to -6%
Queue Warning (23)	Technology Freight	Active Traffic Management	Corridor	Crashes: -20 to -46%	Region	-5%
					Region Non-Recurring	-10%
					Local	-5 to -10%
					Local Non-Recurring	-10 to -20%
Ramp Flow Control (10,24)	Technology	Active Traffic Management	Corridor	Travel Time: -17% to 22% Throughput: +16% Speeds: +8% Crashes: -12 to -21% *Total Delay: -18% *Vehicle Hours Traveled: -5.5%	Region	-10%
					Region Recurring	-10%
					Region Non-Recurring	-10%
					Local	-10 to -20%
					Local Recurring	-10 to -25%
					Local Non-Recurring	-10 to -15%
Variable Speed Limits (25)	Technology	Active Traffic Management	Corridor	Travel Time: -5 to -15% Throughput: +5% Emissions: -2 to -8% Crashes: -10 to -30% Public Perception of Safety: +46% Capacity: +0 to 10%	Region	-5%
					Region Recurring	-10%
					Local	-5 to -10%
					Local Recurring	-10 to -15%
Pay to Drive Off-Peak (26,27,28,29,30)	Congestion	Pricing Strategies	Corridor Regional	Travel Time Choice: +13 to +21%	Region	-2%
					Region Recurring	-5%
					Local	-2 to -5%
					Local Recurring	-2 to -10%
Pay-As-You-Drive Auto Insurance (31)	Congestion	Pricing Strategies	Regional	Traveler Reduction: -8%	Region	-1%
					Region Recurring	-2%
					Local	-1%
					Local Recurring	-2%
Variable Pricing (32,33,34,35)	Congestion Technology	Pricing Strategies	Spot Corridor	Parking Search Time: -15%	Region	-2%
					Region Recurring	-5%
					Local	-2 to -4%
					Local Recurring	-3 to -10%
Parking Management (36,37)	Congestion Policy	Pricing Strategies	Local	Congestion: -15 to -25% Traffic Accidents: -15 to -25% Emissions: -15 to -25%	Region	-1%
					Region Recurring	-2%
					Local	-1 to -2%
					Local Recurring	-2 to -4%
Construction Contracting Options (38,39,40)	Congestion Policy	Construction Improvements	Spot	Closure Time: -80% Road User and Agency Cost: -25 to -30%	Region	-1%
					Region Recurring	-2%
					Local	-2 to -5%
					Local Recurring	-5 to -10%

Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
Pavement Recycling (41)	Congestion	Construction Improvements	Corridor	Construction Costs: -40 to -50% Construction Time: -60% Emissions: -50%	Region Region Recurring Local Local Recurring	-2% -4% -2 to -5% -5 to -10%
Reducing Construction/Maintenance Disruption (42,43,44)	Congestion	Construction Improvements	Spot Corridor	*Speed: +6 *Braking Force: -34%	Region Region Recurring Region Non-Recurring Local Local Recurring Local Non-Recurring	-2% -2% -2% -2 to -5% -5 to -10% -5 to -10%
Shoulder Pavement Upgrades (45)	Congestion	Construction Improvements	Corridor	Crashes: -3 to -75%	Region Region Recurring Region Non-Recurring Local Local Recurring Local Non-Recurring	-2% -2% -2% -2 to -5% -5 to -10% -5 to -10%
Sustainable Pavements (46)	Congestion	Construction Improvements	Corridor	Peak Period Delay: -7 to -80%	Region Region Recurring Local Local Recurring	-2% -4% -2 to -5% -5 to -10%
Continuous Flow Intersections (47,48)	Congestion	System Modification	Spot	Capacity: +30 to +60% Travel Time: -30 to 50% Crashes: -60%	Region Region Recurring Region Non-Recurring Local Local Recurring Local Non-Recurring	-15% -10% -20% -10 to -25% -5 to -20% -10 to -30%
Median U-Turns (7,49,50,51,47,48,52)	Congestion	System Modification	Spot	Peak Period Delay: -60% Capacity Increase: +20 to +50% Crashes: -30 to -60%	Region Region Recurring Region Non-Recurring Local Local Recurring Local Non-Recurring	-10% -10% -10% -10 to -20% -10 to -30% -10 to -20%
Quadrant Intersections (7,47,52,53)	Congestion	System Modification	Spot Corridor	Capacity: +40% Travel Time: -5 to -20%	Region Region Recurring Region Non-Recurring Local Local Recurring Local Non-Recurring	-17% -20% -15% -15 to -25% -10 to -30% -10 to -20%
Roundabouts (7,52)	Congestion	System Modification	Spot Corridor	Peak Period Delay: -20 to -89% Non-Recurring Delay: -65% Capacity: -22% Crashes: -37 to -75% Fatalities: -90% Emissions: -68%	Region Region Recurring Region Non-Recurring Local Local Recurring Local Non-Recurring	-17% -20% -15% -10 to -25% -10 to -30% -10 to -20%
Intersection Turn Lanes (2,52,54,55,56,57)	Congestion	System Modification	Spot	Lane Capacity: +40 to +60% Capacity: +15 to +25% Crashes: -20 to -35%	Region Region Recurring Region Non-Recurring Local	-15% -15% -15% -10 to -30%

Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
					Local Recurring	-10 to -30%
					Local Non-Recurring	-10 to -30%
Loop Ramps Reducing Left Turns (52)	Congestion	System Modification	Spot Corridor	Alternative Mode: +130%	Region	-15%
					Region Recurring	-10%
					Region Non-Recurring	-20%
					Local	-15 to -20%
					Local Recurring	-10 to -20%
					Local Non-Recurring	-10 to -30%
One-Way Streets (58,59)	Congestion	System Modification	Spot	Capacity: +20 to +50% Crashes: -38%	Region	-10%
					Region Recurring	-10%
					Region Non-Recurring	-10%
					Local	-5 to -20%
					Local Recurring	-5 to -20%
					Local Non-Recurring	-5 to -20%
Superstreets (47,60)	Congestion	System Modification	Corridor	Travel Time: -20% Crashes: -46 to -63%	Region	-10%
					Region Recurring	-20%
					Local	-10 to -20%
					Local Recurring	-10 to -30%
Freight Rail Improvements (61)	Freight	System Modification	Regional	Fuel Consumption: -170 million gallons Emissions: -2 million tons	Region	-1%
					Region Recurring	-2%
					Local	-2 to -5%
					Local Recurring	-2 to -5%
Commercial Vehicle Accommodations (62,63)	Freight	System Modification	Spot	Travel Time: -75%	Region	-1%
					Region Recurring	-2%
					Local	-2 to -5%
					Local Recurring	-2 to -5%
Truck Incentives & Use Restrictions (64,65)	Freight	Traffic Management	Regional	Peak Period Delay: -30 to -40% Crashes: -23 to -68% Emissions: -4 to -5%	Region	-2%
					Region Recurring	-4%
					Local	-2 to -5%
					Local Recurring	-2 to -10%
Truck Lane Restrictions (66,67,68)	Freight	Traffic Management	Corridor	Peak Period Delay: -40% Travel Time: -8 to -15% Crashes: -3.3 to -78%	Region	-1%
					Region Recurring	-3%
					Local	-2 to -5%
					Local Recurring	-2 to -10%
Signal Operations & Management (69,70,71)	Congestion Technology	Traffic Management	Spot Corridor	Peak Period Delay: -11 to -37% Non-Recurring Delay: 560 hours Time Travel: -7.2 to -15% Alternative Mode: +15 to +37% Crashes: -31 to -40% Emissions: -8.6 to -9.1 Gas Consumption: -19%	Region	-7%
					Region Recurring	-10%
					Region Non-Recurring	-5%
					Local	-5 to -20%
					Local Recurring	-5 to -20%
					Local Non-Recurring	-5 to -15%
Aggressive Incident Clearance (72,73,74)	Congestion	Traffic Management	Regional	Crashes: -30% Incident Duration: -11% to -71%	Region	-8%
					Region Non-Recurring	-15%
					Local	-5 to -15%
					Local Non-Recurring	-10 to -30%

Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
Special Event Management	Congestion	Traffic Management	Spot	Peak Hour Duration Delay Reduction: 1.02 Delay Reduction: 33%	Region	-5%
					Region Recurring	-5%
					Region Non-Recurring	-5%
					Local	-5 to -10%
					Local Recurring	-5 to -10%
Local Non-Recurring	-5 to -15%					
Road Weather Management (7,75)	Congestion	Traffic Management	Corridor	Peak Period Delay: -25% Average Speed: +13 to +35% Travel Time: +1 to +40% Total Crashes: -10%	Region	-5%
					Region Recurring	-5%
					Region Non-Recurring	-5%
					Local	-5 to -10%
					Local Recurring	-5 to -10%
Local Non-Recurring	-5 to -10%					

Electronic Toll Collection Systems (76,77)	Technology	Traffic Management	Corridor	Peak Period Delay: -30% Travel Time: -25% Alternative Mode: +15 to +60% Emissions: -16%	Region	-25%
					Region Recurring	-40%
					Region Non-Recurring	-10%
					Local	-20 to -40%
					Local Recurring	-25 to -75%
Local Non-Recurring	-10 to -25%					
Reversible Traffic Lanes (Changeable Lane Assignments) (52,78)	Technology	Traffic Management	Corridor	Peak Period Delay: -30 to -85% Average Speed: +8%	Region	-10%
					Region Recurring	-20%
					Local	-10 to -20%
					Local Recurring	-10 to -30%
Traffic Management Centers (79,80,81)	Technology	Traffic Management	Regional	Peak Period Delay: -50% Volume: -22% Average Speed: +3 to +19% Travel Time: -9 to -16% Crashes: -15%	Region	-10%
					Region Recurring	-5%
					Region Non-Recurring	-15%
					Local	-10 to -20%
					Local Recurring	-5 to -15%
Local Non-Recurring	-10 to -25%					
Traveler Information Systems (82,83,84)	Technology	Traffic Management	Regional	Non-Recurring Delay: -20 to -27% Travel Time: -9%	Region	-10%
					Region Recurring	-5%
					Region Non-Recurring	-10%
					Local	-5 to -15%
					Local Recurring	-5 to -10%
Local Non-Recurring	-5 to -15%					
Integrated Corridor Management (85)	Technology	Traffic Management	Corridor	Peak Period Delay: -8 to -26% Speed: +7% Crashes: -3 to -50% Reliability: 3-10%* Travel Time: 9-29%* Total Delay: 26%*	Region	-15%
					Region Recurring	-10%
					Region Non-Recurring	-20%
					Local	-10 to -20%
					Local Recurring	-5 to -15%
Local Non-Recurring	-10 to -30%					
Express Bus Service (86,87)	Congestion	Transit	Corridor	Service Usage: +112%	Region	-2%
					Region Recurring	-5%
					Local	-2 to -5%
					Local Recurring	-5 to -10%
Park-and-Ride Lots (86,88,89)	Congestion	Transit	Corridor	Former Drive Alone Users: 30% to 46%	Region	-1%
					Region Recurring	-2%

Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
					Local	-1 to -3%
					Local Recurring	-1 to -3%
Heavy Rail (90,91)	Congestion	Transit	Regional	Total Delay: -67,200 Passengers Per Hour	Region	-5%
					Region Recurring	-10%
					Local	-5 to -10%
					Local Recurring	-10 to -20%
Commuter Rail (92)	Congestion	Transit	Regional	Vehicle Miles Traveled: -0.5% Alternative Mode: +50%	Region	-5%
					Region Recurring	-10%
					Local	-5 to -10%
					Local Recurring	-10 to -20%
Light Rail (93)	Congestion	Transit	Corridor Local Regional	Fatalities: -36%	Region	-2%
					Region Recurring	-4%
					Local	-1 to -3%
					Local Recurring	-2 to -8%
Bus Rapid Transit (94,95,96,97,98,99,100)	Congestion	Transit	Local	Travel Time: -20 to -40% Alternative Mode: +20 to +30% Crashes: -64% Fatalities: -88%	Region	-2%
					Region Recurring	-4%
					Local	-1 to -3%
					Local Recurring	-2 to -8%
Local Bus Service (101,102)	Congestion	Transit	Local	Alternative Fuels: +10%	Region	-1%
					Region Recurring	-1%
					Local	-1%
					Local Recurring	-1%
Circulator Bus Transit (103)	Congestion	Transit	Local	Accidents Per 10,000 Miles: 0.32 to 1.24	Region	-1%
					Region Recurring	-1%
					Local	-1%
					Local Recurring	-1%
Demand Response Transit (104)	Congestion	Transit	Regional	Alternative Mode Increase: +10 to +20%	Region	-0.5%
					Region Recurring	-1%
					Local	-0.5%
					Local Recurring	-1%
Rural Transit (105,106,107,108)	Congestion	Transit	Regional	Speed: +14% Travel Time: -8 minutes Alternative Mode: +22 to +34.5	Region	-0.5%
					Region Recurring	-1%
					Local	-0.5%
					Local Recurring	-1%
Technology-Based Transit Improvements (109,110,111,112,113,114,115)	Congestion Technology	Transit	Regional	SmarTrip Usage: 62%	Region	-1%
					Region Recurring	-2%
					Local	-1 to -2%
					Local Recurring	-2 to -4%
Fare Strategies (116,117,118,119)	Congestion	Transit Parking Strategies	Local Regional	Peak Period Delay: -4 to -30% Volume: -30% Alternative Mode: -16 to -90%	Region	-1%
					Region Recurring	-2%
					Local	-1%
					Local Recurring	-2%
Multimodal Transportation Centers (120)	Congestion	Transit	Corridor	Peak Period Delay: -30 to -35% Travel Time: -15 to -19%	Region	-2%
					Region Recurring	-5%
					Local	-1 to -3%
					Local Recurring	-2 to -8%

Congestion Strategy	Area	Congestion Strategy Sub-Category	Geographical Impact	Impact Findings	Delay Measure	Percent Recommendation
Active Demand Management (30,121,122)	Technology	Travel Options	Regional	Crashes: -11%	Region	-2%
					Region Recurring	-3%
					Local	-1 to -3%
					Local Recurring	-2 to -5%
Carpooling (123,124,125,126,127,128,129,130)	Congestion	Travel Options	Regional	Peak Period Delay: -18 to -25% Volume: -5 to -23%	Region	-2%
					Region Recurring	-4%
					Local	-1 to -3%
					Local Recurring	-3 to -8%
Real-Time Ridesharing (124,131,132,133,134,135)	Congestion Technology	Travel Options	Regional	Vehicle Miles Traveled: -6 to -27%	Region	-1%
					Region Recurring	-2%
					Local	-1 to -3%
					Local Recurring	-2 to -5%
Vanpooling (7,124)	Congestion	Travel Options	Regional	Miles Traveled: -35 million to -55 million Speed: +37 miles per hour	Region	-1%
					Region Recurring	-2%
					Local	-1 to -3%
					Local Recurring	-2 to -5%
Flexible Work Hours (7)	Congestion	Travel Options	Regional	Fuel Consumption: -774,000 gallons Emissions: -4,546 metric tons	Region	-4%
					Region Recurring	-8%
					Local	-5 to -10%
					Local Recurring	-5 to -15%
Compressed Work Weeks (7)	Congestion	Travel Options	Regional	Vehicle Miles Traveled: -144,700 miles/year	Region	-4%
					Region Recurring	-8%
					Local	-5 to -10%
					Local Recurring	-5 to -15%
Telecommuting (7)	Congestion Technology	Travel Options	Regional	Travel Time: -30%	Region	-4%
					Region Recurring	-8%
					Local	-2 to -8%
					Local Recurring	-5 to -15%
Transportation Management Associations (129,136,137,138)	Policy	Travel Options	Regional	Vehicle Miles Traveled: -4.42 million Speed: -11 to -19 miles per hour Alternative Mode: +52%	Region	-2%
					Region Recurring	-4%
					Local	-1 to -3%
					Local Recurring	-2 to -5%
Trip Reduction Options (7)	Policy	Travel Options	Regional	Peak Period Delay: -8% Volume: -12% Alternative Mode: +17 to +64%	Region	-2%
					Region Recurring	-4%
					Local	-1 to -3%
					Local Recurring	-2 to -5%
State Employee Trip Reduction (7,139,140,141)	Policy	Travel Options	Regional	Drive-alone: -4 to -6% Emissions: -12%	Region	-2%
					Region Recurring	-4%
					Local	-1 to -3%
					Local Recurring	-2 to -5%

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Appendix B: FIXiT Calculation Equations



Step C1: Calculate Delay Reduction Benefits by Segment

Note 1: Default Delay Split is Recurring Delay 50% and Non-Recurring Delay 50%.

1. Peak Period Annual Hours of Delay (person-hours)

1.1 Total Delay Reduction

1.1.1 Low Scenario

Equation 1 = Recurring Delay Reduction under Low Scenario + Non-recurring Reduction under Low Scenario

1.1.2 High Scenario

Equation 2 = Recurring Delay Reduction under High Scenario + Non-recurring Reduction under High Scenario

1.2 Recurring Delay Reduction

1.2.1 Low Scenario

Equation 3 = Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under Low Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario

1.2.2 High Scenario

Equation 4 = Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under High Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario

1.3 Non-recurring Reduction

1.3.1 Low Scenario

Equation 5 = Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under Low Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario

1.3.2 High Scenario

Equation 6 = Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under High Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario

2. Non-Peak Period Annual Hours of Delay (person-hours)

2.1 Total Delay Reduction

2.1.1 Low Scenario

Equation 7 = Recurring Delay Reduction under Low Scenario + Non-recurring Reduction under Low Scenario

2.1.2 High Scenario

Equation 8 = Recurring Delay Reduction under High Scenario + Non-recurring Reduction under High Scenario

2.2 Recurring Delay Reduction

2.2.1 Low Scenario

Equation 9 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under Low Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario

2.2.2 High Scenario

Equation 10 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under High Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario

2.3 Non-recurring Reduction

2.3.1 Low Scenario

Equation 11 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under Low Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario

2.3.2 High Scenario

Equation 12 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under High Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario

3. Total Annual Hours of Delay (person-hours)

3.1 Total Delay Reduction

3.1.1 Low Scenario

Equation 13 = Recurring Delay Reduction under Low Scenario + Non-recurring Reduction under Low Scenario

3.1.2 High Scenario

Equation 14 = Recurring Delay Reduction under High Scenario + Non-recurring Reduction under High Scenario

3.2 Recurring Delay Reduction

3.2.1 Low Scenario

Equation 15 = Total Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under Low Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario

3.2.2 High Scenario

Equation 16 = Total Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under High Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario

3.3 Non-recurring Reduction

3.3.1 Low Scenario

Equation 17 = Total Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under Low Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario

3.3.2 High Scenario

Equation 18 = Total Annual Hours of Delay (person-hours) * 50%¹ * Strategy #1 Delay Reduction Number under High Scenario * Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario * Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario

Step C2: Calculate Delay Reduction Benefits by Urban Area

Note 2: Default Delay Split is Recurring Delay 50% and Non-Recurring Delay 50%.

1. Peak Period Annual Hours of Delay (person-hours)

1.1 Total Delay Reduction

1.1.1 Low Scenario

Equation 19 = Recurring Delay Reduction under Low Scenario + Non-recurring Reduction under Low Scenario

1.1.2 High Scenario

Equation 20 = Recurring Delay Reduction under High Scenario + Non-recurring Reduction under High Scenario

1.2 Recurring Delay Reduction

1.2.1 Low Scenario

Equation 21 = Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under Low Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario}

1.2.2 High Scenario

Equation 22 = Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under High Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario}

1.3 Non-recurring Reduction

1.3.1 Low Scenario

Equation 23 = Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under Low Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario}

1.3.2 High Scenario

Equation 24 = Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under High Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario}

2. Non-Peak Period Annual Hours of Delay (person-hours)

2.1 Total Delay Reduction

2.1.1 Low Scenario

Equation 25 = Recurring Delay Reduction under Low Scenario + Non-recurring Reduction under Low Scenario

2.1.2 High Scenario

Equation 26 = Recurring Delay Reduction under High Scenario + Non-recurring Reduction under High Scenario

2.2 Recurring Delay Reduction

2.2.1 Low Scenario

Equation 27 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under Low Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario}

2.2.2 High Scenario

Equation 28 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under High Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario}

2.3 Non-recurring Reduction

2.3.1 Low Scenario

Equation 29 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under Low Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario}

2.3.2 High Scenario

Equation 30 = Non-Peak Period Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under High Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario}

3. Total Annual Hours of Delay (person-hours)

3.1 Total Delay Reduction

3.1.1 Low Scenario

Equation 31 = Recurring Delay Reduction under Low Scenario + Non-recurring Reduction under Low Scenario

3.1.2 High Scenario

Equation 32 = Recurring Delay Reduction under High Scenario + Non-recurring Reduction under High Scenario

3.2 Recurring Delay Reduction

3.2.1 Low Scenario

Equation 33 = Total Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under Low Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario}

3.2.2 High Scenario

Equation 34 = Total Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under High Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario}

3.3 Non-recurring Reduction

3.3.1 Low Scenario

Equation 35 = Total Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under Low Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under Low Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under Low Scenario}

3.3.2 High Scenario

Equation 36 = Total Annual Hours of Delay (person-hours) * 50%² * {Strategy #1 Delay Reduction Number under High Scenario + Depreciation Value #1 * Strategy #2 Delay Reduction Number under High Scenario + Depreciation Value #2 * Strategy #3 Delay Reduction Number under High Scenario}