# @@ 1 INTRODUCTION

FTOT is a flexible scenario-testing tool that optimizes the transportation of materials for future energy and freight scenarios. FTOT models and tracks commodity-specific information and can take into account conversion of raw materials to products (e.g., crude oil to jet fuel and diesel) and the fulfillment of downstream demand. FTOT was developed at the US Department of Transportation's Volpe National Transportation Systems Center in support of the Federal Aviation Administration, the Department of Energy, and the Office of Naval Research.

This user guide document provides comprehensive details for how users can interact with FTOT to run their own scenarios. Section 2 explains how to install FTOT. Section 3 details how to customize FTOT inputs to run a basic scenario. Section 4 explains the configurations needed to run more advanced FTOT scenarios (e.g., customizing the GIS network, incorporating schedules). Section 5 guides the user through manually running an FTOT scenario. Section 6 describes the FTOT outputs and explains the interpretation of each output. Section 7 details the various FTOT supplementary tools that supplement the core tool. Section 8 provides a troubleshooting guide. Appendix A contains legacy installation instructions for older versions of ArcGIS. Appendix B provides full documentation of the scenario XML input file.

New FTOT functionalities and user materials are added every quarterly release. Specific details on updates associated with the latest release (and previous releases) can be found in the change log on the GitHub code hosting site at https://github.com/VolpeUSDOT/FTOT-Public/releases.

# @@ 2 INSTALLATION

Current FTOT installation instructions can be found below. **FTOT Version 2022.2** can be downloaded from the Public GitHub repository (https://github.com/VolpeUSDOT/FTOT-Public). Before running a scenario in FTOT, the following programs must be installed:

- **ESRI ArcGIS Pro** Version 2.6 or higher (Geographic Information System (GIS) Program) performs the geospatial analysis elements of the tool. The Advanced License level of ArcGIS Pro is strongly recommended, though FTOT may function (without full support) on lower license levels (basic or standard). An installation of ArcGIS Pro is accompanied by a **base Python installation** (Version 3.6), providing the majority of Python modules required for FTOT scripts to run. FTOT's installation process automatically generates a standalone FTOT Python environment based on the ArcGIS Pro default Python environment. Special attention should be paid to this Python environment. See the troubleshooting section for issues with pre-installed Python environments.
- **SQLite** is used to store scenario variables and results. In order for the user to fully explore SQLite-generated outputs, users are encouraged to install a SQLite database browser, such as DB Browser for SQLite.
- A **Tableau dashboard** is used to generate a suite of graphical outputs based on the optimal scenario solution. To view the Tableau dashboard, one can use either the free Tableau Reader or a full version of Tableau Desktop v2019.4 or higher.

During the FTOT installation process, the following packages are installed and placed in the Python environment. Package versions that have been tested and are compatible with FTOT Version 2022.2 are:

- **NetworkX** is an open-source Python-based suite of tools for manipulating and analyzing complex networks for which many publicly available algorithms and tools have been established. Versions 2.4-2.5 has been tested to be compatible with FTOT Version 2022.2.
- **PuLP** (Open Source Python Wrapper for Optimization Solvers) is a linear programming module written in Python. Versions 2.4-2.6 have been tested to be compatible with FTOT Version 2022.2. In FTOT, PuLP is used to link the solvers in the Computational Infrastructure for Operations Research project (COIN-OR). The **COIN-OR** project maintains an archive of open-source software for operations research, including implementations of algorithmic solvers and modeling systems. This includes a number of open-source optimization models, including a branch and cut solver (CBC) for mixed integer programming.
- **Lxml** is a Python package for handling XML and is used in FTOT to parse the scenario configuration file. Versions 4.5.2, 4.6.3, and 4.8.0 have been tested to be compatible with FTOT Version 2022.2.
- **Pint** is a Python package for unit conversions and dimensionality checks. It is used throughout FTOT to harmonize user input data into a common set of units for solids and liquid freight movements. Versions 0.16-0.18 have been tested to be compatible with FTOT Version 2022.2.
- **Imageio** is a Python package required for creating animated graphics of FTOT mapping outputs. Version 2.9.0 has been tested to be compatible with FTOT Version 2022.2.

## 2.1 Installing ESRI ArcGIS Pro

ESRI ArcGIS Pro Version 2.6 or higher (Geographic Information System (GIS) Program) performs the geospatial analysis elements of the tool.

While FTOT will function with any license-level of ArcGIS Pro (Basic, Standard, or Advanced), the Advanced license level of ArcGIS Pro is highly recommended. Unexpected behavior and/or performance issues may emerge with a Basic or Standard license, and support is more limited.

- Contact your system administrator for help in installing and licensing the software.
- All defaults can be accepted during installation. The process will involve installing two files—one exe file for the major version (e.g., ArcGIS Pro 2.6) and a patch/msp file representing the minor version (e.g., ArcGIS Pro 2.6.3).
- The install may take a while.
- If you are upgrading from an earlier version of ArcGIS Pro, the upgrade will remove your old version automatically.
- After installation is complete, make sure you properly set up the license authorizing the software. Users should contact their system administrator for detailed instructions on activating the ArcGIS Pro license. Note that FTOT is compatible with any ArcGIS license level (Basic, Standard, Advanced). However, it is generally advised that users select the highest-level license available, and full support and functionality for FTOT is only available with the Advanced license.

## 2.2 Installing FTOT

**Download FTOT repository**

1. To install FTOT, navigate to the FTOT repository on GitHub: https://github.com/VolpeUSDOT/FTOT-Public
2. Click the Code dropdown and select “Download Zip” (Figure 1).

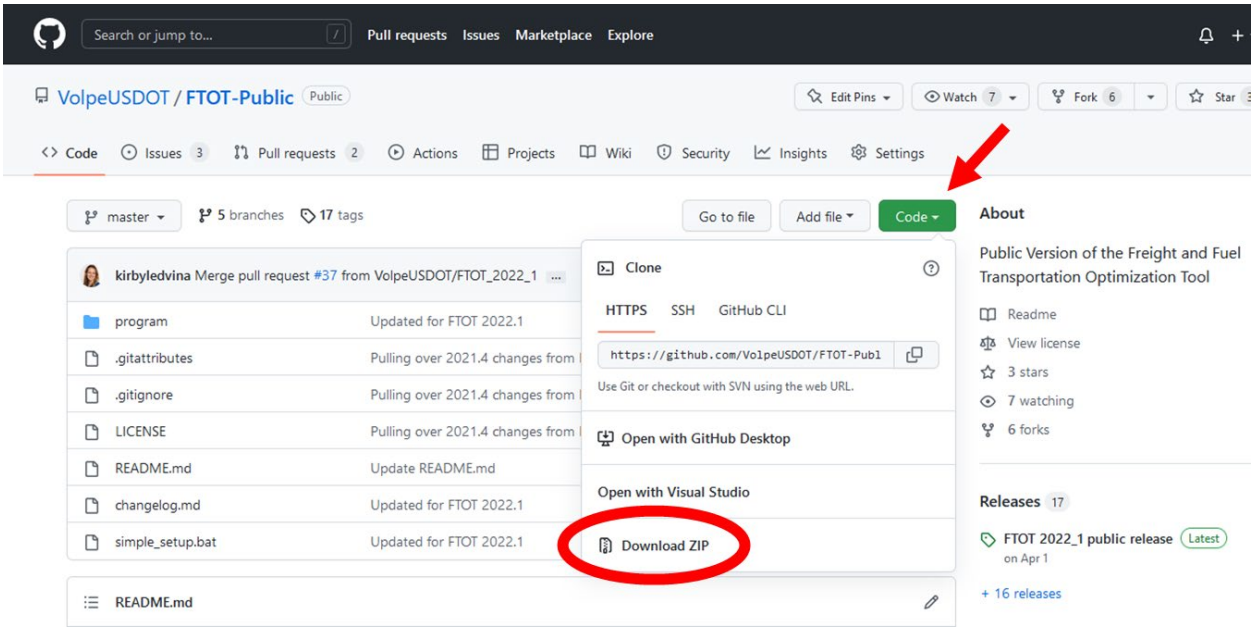



**Figure 1: Screenshot of Download ZIP functionality on GitHub.**

3. Unzip the contents into the following directory on your local machine: C:\FTOT
    - Note: On some systems the FTOT directory may need to be renamed from FTOT-Public-Master.
    - Ensure that the first layer inside C:\FTOT includes a subfolder called “program”, a file named “simple_setup.bat”, and two additional files named “.gitignore” and “.gitattributes” among other individual files. The contents may need to be moved into this configuration if they did not unzip this way automatically.

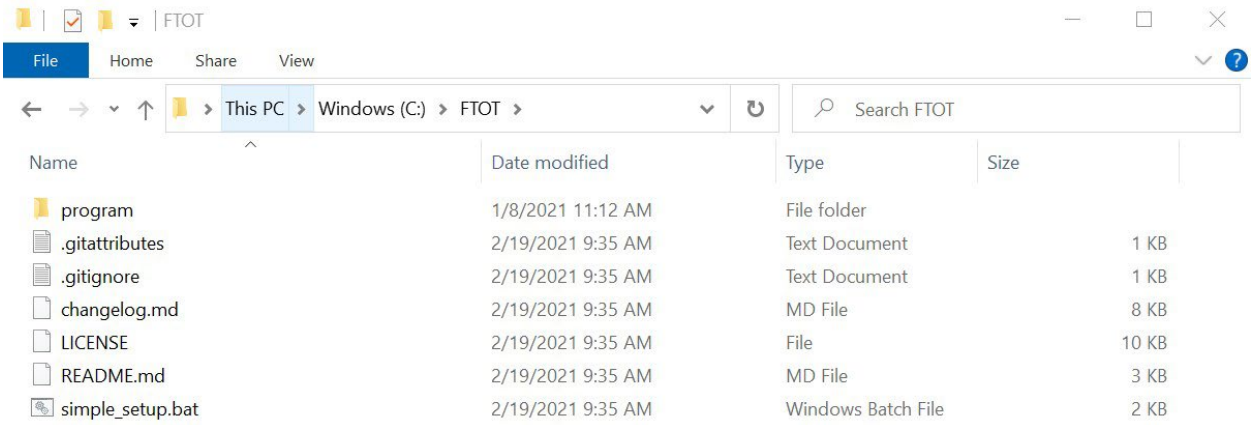



**Figure 2: Screenshot of FTOT directory structure.**

### Install FTOT's Python dependencies

4. Open a command line window by clicking on the Windows Start Menu, searching for “Command Prompt”, and clicking on it.

5. Click and drag the file “simple_setup.bat” from the C:\FTOT folder to the command line window, and press enter in the command line window.
6. The script will create a new FTOT-specific Python 3 environment derived from ArcGIS Pro's installation of Python and install it in C:\FTOT\python3_env. Cloning the Python 3 environment (see screenshot in Figure 3) may take a few minutes.

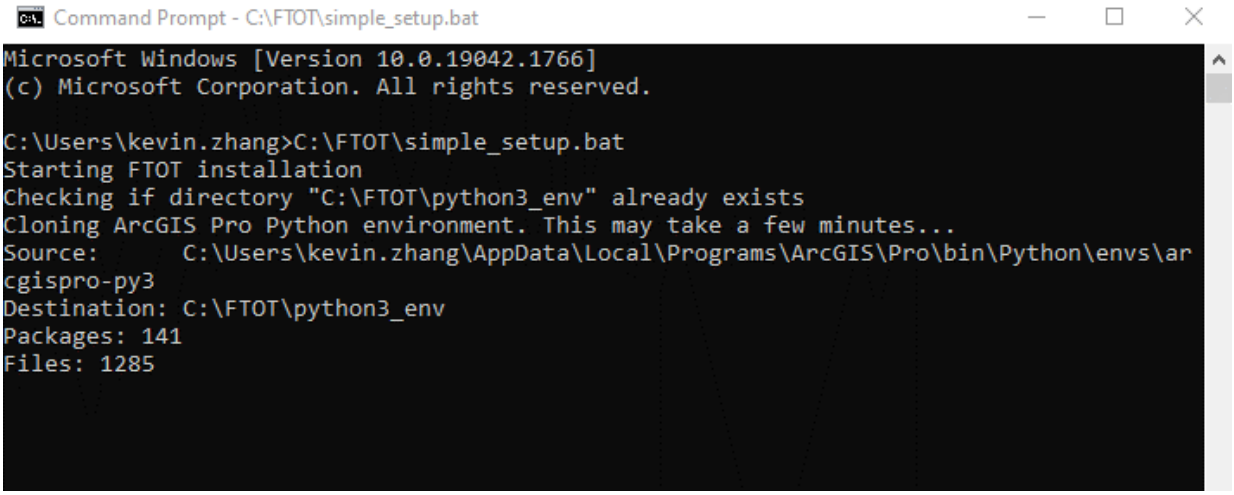



Figure 3: Screenshot of the command line window during setup of the FTOT Python environment.

7. When all dependencies are installed, the command line window will print “Complete” and prompt you to press any key to exit the installation. The Python executable file for the newly installed environment is located at C:\FTOT\python3_env\python.exe.

Note: Steps 4-7 above need to be re-run each time you install a new version of ArcGIS Pro. If the FTOT-specific Python 3 environment already exists, the setup script will ask to delete the existing C:\FTOT\python3_env directory before creating a new installation (see Figure 4 for message).

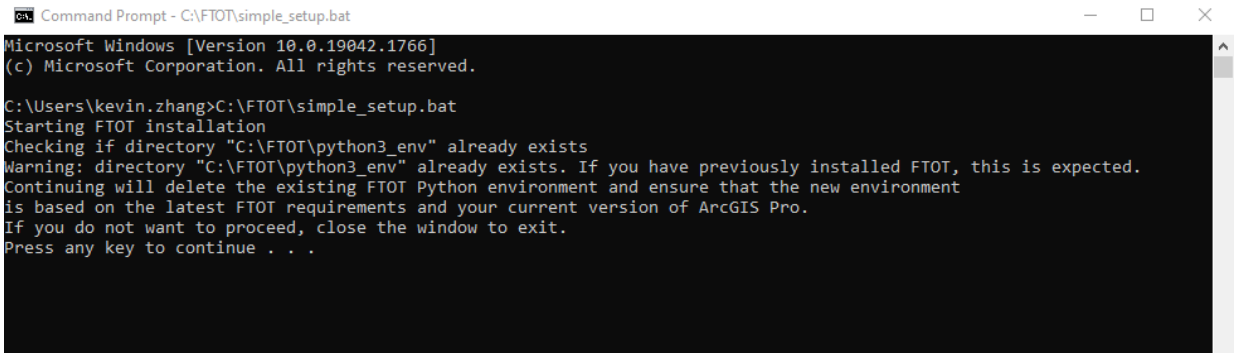



Figure 4: Screenshot of the command line window confirming deletion of previous Python environment.

**Download FTOT datasets**

8. Additional transportation network data is required to run FTOT. In addition, documentation and supplementary scenario data are provided to acclimate you to running FTOT. This

documentation and scenario dataset can be downloaded directly from https://volpeusdot.github.io/FTOT-Public/data_download.html. Only the most recent version of the zip file needs to be downloaded.

9. Extract the contents to within the C:\FTOT directory on your machine. After you download and save this data, your C:\FTOT directory should contain a scenarios folder and a documentation folder in addition to the existing folder and files.

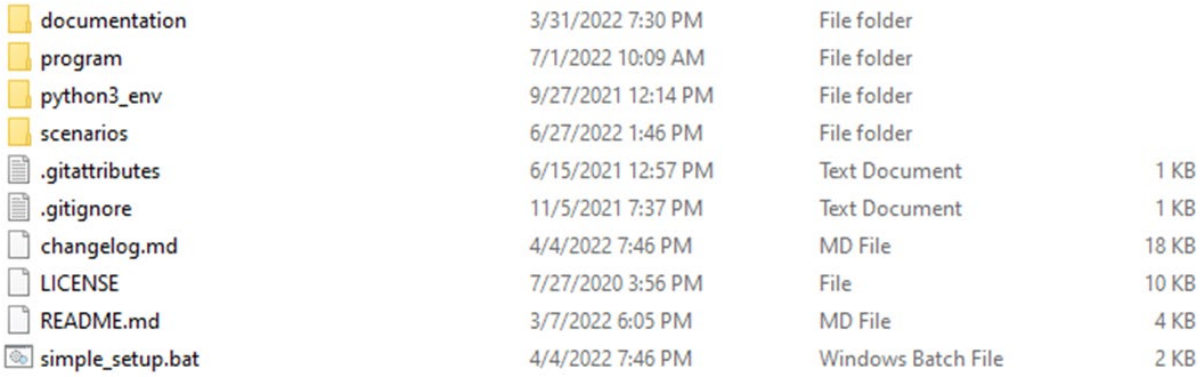



**Figure 5: Screenshot of FTOT directory structure after download of documentation and scenario dataset.**

Inside the scenarios folder should be a common_data folder along with directories containing quick start and reference scenarios. The user is strongly encouraged to walk through the Quick Start examples after installation and before creating their own scenarios in order to test that FTOT was installed correctly and to get used to the process and structure of an FTOT scenario.

## 2.3 Installing Tableau

Tableau dashboard outputs (Section 6.2) will not be fully functional until you have installed Tableau Desktop or Tableau Reader. If Tableau is not available at your organization, install the free software, Tableau Reader, which can be downloaded here: https://www.tableau.com/products/reader. To install the software, follow the provided instructions.

# @@ 3 SETTING UP A STANDARD SCENARIO

This section describes how to edit FTOT configuration files and inputs the user will need to create their own scenarios. Section 4 details how to configure FTOT inputs for more complex FTOT functionalities, which the user can reference as needed for their own scenario.

FTOT's Quick Start and Reference Scenarios datasets include several ready-to-use example scenarios and input files. See https://volpeusdot.github.io/FTOT-Public/data_download.html for the latest scenario and documentation files. In addition to demonstrating FTOT functionalities, the Quick Start and Reference Scenarios can also serve as templates for creating user-specified scenario configuration and input files.

**Getting Started**

FTOT's Quick Start and Reference Scenarios are stored in the C:\FTOT\scenarios\quick_start and C:\FTOT\scenarios\reference_scenarios folders, respectively, once downloaded. Each scenario includes its own dedicated subfolder for storing the scenario configuration, inputs, and outputs. Each unique FTOT scenario requires a batch (.bat) file, a scenario XML file, and an 'input_data' directory with the relevant facility-commodity input CSV files.

A batch file is a file used to run FTOT in a command-line interface (see Section 5 for more information on this file and how it works). A scenario XML configuration file defines key input parameters applied to the network and optimization. FTOT scenarios also require geospatial information for the network itself (associated network attributes such as costs, impedances and weightings, capacity, movement restrictions, and schedules are specified in the scenario XML). The FTOT network inputs must also include the facilities (origins, processors/waypoints, destinations) associated with the supply chain being analyzed, as well as their associated attributes such as facility minimum and maximum size, available supply/demand of input and output commodities, and associated efficiency/conversion to products. This facility-level supply chain data is defined in a set of comma-delimited files.

To ensure you have all necessary files to run a new FTOT scenario, the user can

1. Copy over a Quick Start or Reference Scenario folder based on the intended supply chain structure of the user's FTOT scenario, and then
2. Customize the starter files according to the user's specific scenario needs.

For example, use files from Quick Start 2 for a scenario where freight flows from a raw material producer (rmp) to a processor (proc) to a destination (dest); use Reference Scenario 2 as a template for a candidate processor generation scenario. To then adapt the starter scenario, the user will need to update the scenario XML (Section 3.1) at a minimum. Most custom scenarios will also require creating new facility-level GIS data (Section 3.2) and supply chain data (Section 3.3). Finally, customization of the scenario's batch file will also be necessary (discussed in detail in Section 5).

## 3.1 XML Schema

A scenario configuration file (e.g., scenario.xml) is used to define the location of key input data such as the multimodal network, facility locations, and facility commodity information defined by the user, as well as key input parameters and assumptions for the run. The scenario configuration file uses the Extensible Markup Language (XML) file format. More details on the XML configuration file are available in Section 3 of the FTOT Technical Documentation, particularly Section 3.10 which describes some of the default parameters and their sources.

The XML configuration file is a text-based file that can be modified in a text editor or an integrated development environment for software development. The user must update the placeholder values in the XML file with scenario specific information, and the default values should be reviewed and adjusted by the user. The XML file is validated against the XML schema file. The 'Master_FTOT_Schema.xsd' schema file is located in the 'lib' folder of the project code repository (e.g., C:\FTOT\program\lib). If the XML scenario file does not meet the requirements set in the schema, FTOT raises an error and reports the offending line and element.

### 3.1.1 Configuring FTOT Scenarios in the XML File

All scenario configurations are through the 'scenario.xml' file. The FTOT XML specifies input data file locations and user variables for the scenario.

#### *3.1.1.1 Checklist of critical items to update for a new scenario*

The following items should be modified by the user for each new scenario XML file:

- `Scenario_Name` (line 4)
- `Scenario_Description` (line 5)
- `RMP_Commodity_Data` (line 22) – Confirm file path.
- `Destinations_Commodity_Data` (line 23) – Confirm file path.
- `Rail_Density_Code_{NUM}_Weight` (lines 83-90) – Please be aware that some Quick Start / Reference Scenarios do NOT use the default rail weights detailed in the documentation, in order to encourage flows on road. Consider changing these weights back to their defaults (1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 10.0) if using a Quick Start or Reference Scenario folder as a template.

Other optional items to update:

- `Disruption_Data` (line 13) – Change file path.
- `Base_RMP_Layer` (line 17) – Change GDB layer if using your own GDB.
- `Base_Destination_Layer` (line 18) – Change GDB layer if using your own GDB.
- `Base_Processors_Layer` (line 19) – Change GDB layer if using your own GDB.
- `Processors_Commodity_Data` (line 24) – Change file path.
- `Processors_Candidate_Commodity_Data` (line 25) – Change file path.
- `Schedule_Data` (line 26) – Change file path.
- `Commodity_Mode_Data` (line 27) – Change file path.

#### *3.1.1.2 Additional variables for scenario configuration*

The XML file includes a total of 85 variables that can be modified by the user to customize the scenario, but many of these can be left at the default values, including:

- Default units for the solid and liquid phases are defined by `Default_Units_Solid_Phase` and `Default_Units_Liquid_Phase` (lines 33-34). Note that the default units for the solid phase of matter is metric tons, whereas input data for Quick Starts and Reference Scenarios are given in Imperial Tons. The user is free to specify facility-commodity data in any units they prefer, with the stipulation that solid materials must be defined in terms of mass and liquids must be defined in terms of volume. FTOT will convert each record to the default scenario units using Pint, a Python module for converting units.
- Impedances: Starting at line 72 in the scenario XML are a series of costs (e.g., `liquid_Railroad_Class_I_Cost`) and weights (e.g., `Rail_Density_Code_7_Weight`), also known as impedances, which help define the costs associated with flowing commodities over the transportation network (see Technical Document, Section 3.10). Dollar costs being equal, segments with lower weights are favored over segments with higher weights. Ultimately, both the dollar and routing costs are reported in the scenario results. For routine runs in FTOT, we recommend increasing weight levels by 0.1 between each category (e.g., 1.0 for the first tier, 1.1 for the second tier, etc.). The rail weights provided in the quick start and reference scenario XMLs are exaggerated to favor flows on the road network, but the user can modify these when exploring different exercises and other scenario variations. In general, a larger increase in weights between categories of the same mode will lead to bigger differences in routing costs between categories; optimal routing will hue closer to lower weighted categories.
- Mode exclusion: To exclude a network mode, the user can edit the Route_Optimization_Script section of the scenario XML file. For example, the road network can be excluded by setting line 151 in the scenario XML file (`Road` in the Permitted_Modes section) to False.
- Enhance run time using network density reduction: In the scenario.xml file, enable the network pre-solve step by setting the `NDR_On` parameter to True (line 147) in order to improve runtime for larger scenarios. Enabling this functionality triggers a network density reduction (NDR) calculation using the NetworkX shortest path algorithm in the G step, which simplifies the optimization problem. Performing the optimization steps on the less dense shortest path network decreases the runtimes of the O steps. NDR cannot be used in combination with candidate generation, capacity constraints, or maximum allowable transport distance.
- Adjust artificial link distance: Artificial links are used by FTOT to connect facilities to each mode in the multimodal network; facilities will only be connected to the road network if there is a road network link within the user-defined artificial link distance from the facility point. FTOT automatically constructs artificial links for each facility and each mode based on the artificial link distance parameter, which the user can set for each mode in lines 132 to 136 o the scenario XML file (e.g., `Road_Max_Artificial_Link_Distance` for the road network). The larger the parameter, the more likely FTOT will be able to find a network link to connect the facility to (but the less realistic the artificial link may be). Changing the artificial link distance parameter can have a couple of outcomes: (1) it can change the set of modes a facility is connected to, (2) it can completely strand a facility in a scenario if no artificial links are constructed.

- Short-haul penalties to reduce spurious mode switching: The short haul penalties (e.g., `liquid_Rail_Short_Haul_Penalty` on line 140) are fixed penalties per unit of flow that are used to prevent very short movements by rail and water, which are usually unrealistic (road is much more commonly used for short freight movements). Short-haul penalties are applied to the network as a routing cost on artificial links connecting facilities to the rail and waterway networks. Routing cost on artificial links for the road network is calculated to be equivalent to one mile on a local road. Routing cost on artificial links for the pipeline network is calculated at $0.19/mile of artificial link, which is the average per-mile cost for a pipeline tariff as calculated from data provided by LawIQ. Artificial links are not associated with a dollar cost since they do not represent physical links in the network.
- Apply capacity constraint to routing: The Capacity_Options section of the scenario XML file starting at line 157 can be modified to set `Capacity_On` to True (which turns on capacity for all links) and to set Background_Flows for each modal network to True (which prompts FTOT to use existing transportation network flows to limit the usable capacity of the network). Both capacity and background flows are based on daily flows, so using capacity in a scenario implies that flows are all happening in a day. Background flows can be turned on by mode, although the public version of FTOT only contains background flows for Road and Water modes. More details on where background flows data are sourced from can be found in the Technical Documentation. The Capacity_Options section also includes the field `Minimum_Capacity_Level`, which is a fraction between 0 and 1 representing the minimum available capacity that FTOT should give any link in the scenario when `Capacity_On` is set to True. When set above 0, this property allows FTOT to flow freight on links that are at or near capacity. When the allowable capacity is 0, this means that FTOT can only use the currently available capacity of the network and cannot route goods along any link that is at or over capacity. A minimum capacity level of 0.25 sets the available capacity of each link in the network to at least 25% of its normal capacity, even for links that would normally be unavailable or capacity constrained based on their capacity and existing background flows. Links with more than 25% available capacity are unaffected.
- Unmet demand penalty: The unmet demand penalty (e.g., `Unmet_Demand_Penalty` on line 175) is a fixed penalty per unit of unmet demand at the destination facilities of the FTOT scenario. This cost penalty is used to drive commodity flow over the network and should be set higher than average transportation cost for the scenario. See Troubleshooting Notes in Section 8 for common issues with the unmet demand penalty. It is advised to run scenarios with multiple unmet demand penalties to explore the sensitivity of a given analysis.

#### *3.1.1.3 Updating FTOT scenarios from older release versions*

The FTOT team often introduces optional XML elements as new features are added to FTOT, so older versions of Quick Start and Reference Scenario XML files may not have all available scenario elements. The quickest way to update an existing, older scenario is to manually add any additional elements needed. For reference, the master XML template saved at `C:/FTOT/program/lib/v6_temp_Scenario.xml` contains all required and optional XML elements.

When updating the XML, the user does NOT need to include any comments from the original XML or in the template XML, but the elements do need to be in the same order as seen in the template.

### 3.1.2 Tools for Updating XML Files

Several tools can help the user efficiently and thoroughly update their new scenario XML (and to a lesser extent, the batch files described further in Section 5). Text file comparisons can help the user recognize items that still need updating. Consider comparing new scenario files to the following:

- **FTOT's template XML**, located in the `C:/FTOT/program/lib` sub-directory. This file (named `v6_temp_Scenario.xml`) can help the user identify missing scenario elements or differences from the Quick Start or Reference Scenario defaults. The file is also used as the template for an FTOT Tool that creates new scenario files from scratch.
- **Previously-created versions** of the scenario being run, including any template Quick Start or Reference Scenario files. This comparison is especially helpful to verify scenario variations and new file paths.

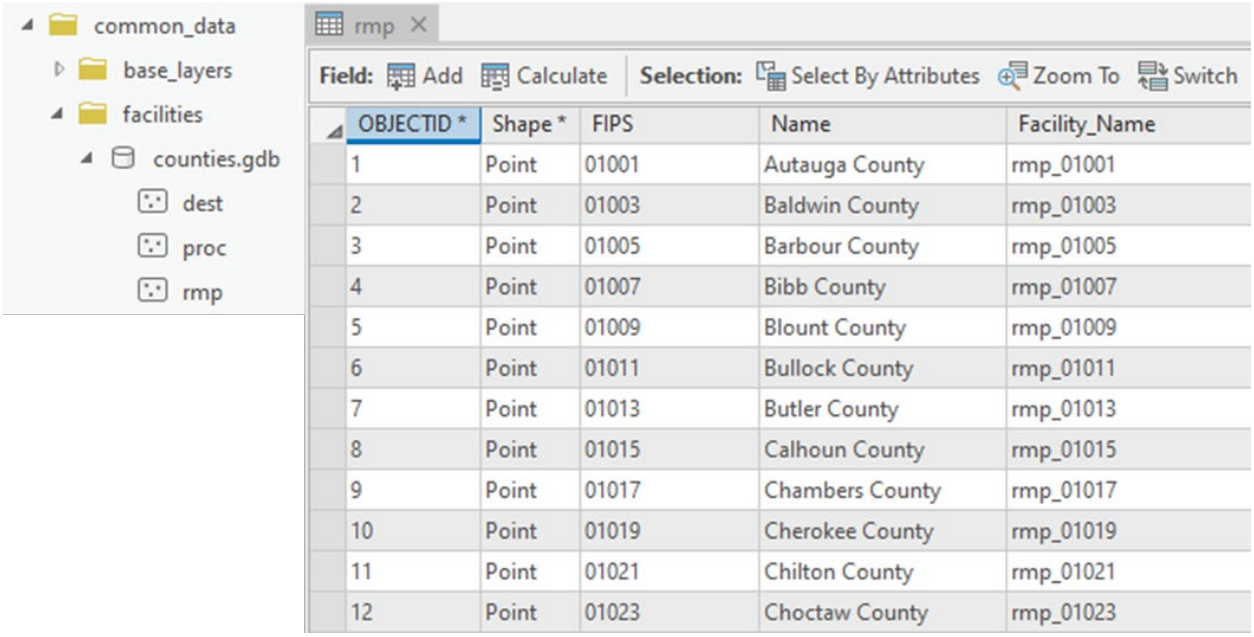
Listed below are just a few tools to update scenario files:

- **Text editor.** Any text editor, such as Windows Notepad, can be used to directly edit XML element values (e.g., file paths).
- **BeyondCompare.** Using the BeyondCompare (https://www.scootersoftware.com/) application, the user can "copy section to right/left" using arrows in the side bar and highlight differences in text (red lines) and in spacing (purple lines). Make sure to separate out distinct sections before copying over to avoid unintentional overwriting. Note: Requires a paid license after a trial period.
- **FTOT Tools.** The XML tool in ftot_tools.py can create a new, blank scenario XML or add missing elements to an existing XML. Make sure to manually check all element values if using this tool. See Section 7.1 for guidance on running FTOT Tools.
- **Visual Studio.** In Visual Studio, go to Tools > Command Line > Developer Command Prompt, and in the window that appears enter `devenv.exe /diff list1.txt list2.txt` replacing list1.txt and list2.txt with the XML or other files the user wishes to compare. The user can drag and drop files to paste in the full file path. A comparison window will open in Visual Studio. See a related Stack Exchange post (https://stackoverflow.com/questions/13752998/compare-two-files-in-visual-studio).

## @@ 3.2 Facility Location GIS Data

FTOT requires GIS-based input datasets containing the facility names and locations of raw material producers (rmp), processors (proc), and destinations (dest). These GIS feature classes (FC) must contain facility names and point locations for each facility. **Note: facility names must be unique**, e.g., Middlesex County CT must be differentiated from Middlesex County MA. FTOT will automatically match the geospatial location specified in the FC to the facility-commodity relationships specified in the CSV files defined below (Section 3.3) using the Facility_Name fields.

There are many sources of GIS data an FTOT user can leverage to represent the locations of a scenario's facilities. FTOT comes with one preexisting facility location geodatabase included in FTOT's common data subdirectory—point-based representations of every county in the United States. All of the Quick Start and Reference Scenarios utilize this data as proxies for hypothetical facility locations. If FTOT was installed in the default location (including the separate download of documentation and scenario datasets available at https://volpeusdot.github.io/FTOT-Public/data_download.html), the county-based facility location geodatabase is stored in the following location: C:\FTOT\scenarios\common_data\facilities\counties.gdb (in previous versions of FTOT this was known as facilities.gdb). The facility location geodatabase included with FTOT is a useful facility location dataset to start with for users working with county-based commodity data who quickly want to get up and running with FTOT. One feature class is provided with unique county-facility names for each facility type (raw material producers, processors, and destinations). The structure of the geodatabase and an example of the records are shown below.




| OBJECTID * | Shape * | FIPS | Name | Facility_Name |
|---|---|---|---|---|
| 1 | Point | 01001 | Autauga County | rmp_01001 |
| 2 | Point | 01003 | Baldwin County | rmp_01003 |
| 3 | Point | 01005 | Barbour County | rmp_01005 |
| 4 | Point | 01007 | Bibb County | rmp_01007 |
| 5 | Point | 01009 | Blount County | rmp_01009 |
| 6 | Point | 01011 | Bullock County | rmp_01011 |
| 7 | Point | 01013 | Butler County | rmp_01013 |
| 8 | Point | 01015 | Calhoun County | rmp_01015 |
| 9 | Point | 01017 | Chambers County | rmp_01017 |
| 10 | Point | 01019 | Cherokee County | rmp_01019 |
| 11 | Point | 01021 | Chilton County | rmp_01021 |
| 12 | Point | 01023 | Choctaw County | rmp_01023 |

**Figure 6: Screenshot of the FTOT counties geodatabase.**

Users basing facility locations on the default data that come packaged with FTOT do not need to move or copy over those data into a new scenario directory; they can continue to be read from their default location (in the `C:/FTOT/scenarios/common_data/facilities` subdirectory). Users who want to create their own customized facility location GIS data should read the next section for guidance on leveraging other facility location data and creating custom facility location data—either based on the default facility location data or built entirely from scratch.

### 3.2.1 Creating Custom Facility Location Data

In some cases, existing GIS-based facility location data relevant to an FTOT scenario may not already exist. The sections below walk the FTOT user through ArcGIS Pro functionality and workflows that help the user build custom facility location data.

**Accessing and Viewing the Template Facility Location Data in ArcGIS Pro**

- Users who installed FTOT in the default location can find the default facility location database in C:\FTOT\scenarios\common_data\facilities\counties.gdb.
- The facilities contained in this geodatabase can easily be viewed, queried, and subset within ArcGIS Pro. Open ArcGIS Pro and create a blank map template, saving the project in a directory of your choice.

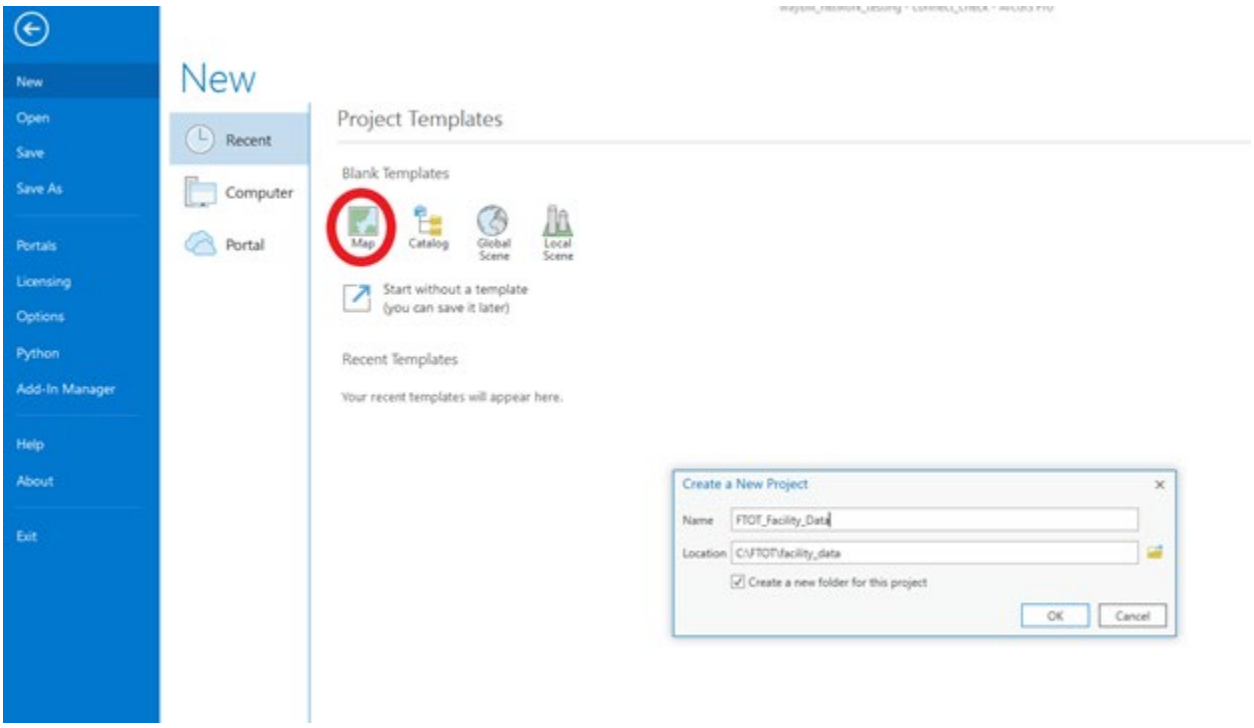



**Figure 7: Screenshot of a new ArcGIS Pro project for facility location data.**

- The three feature classes inside this geodatabase can be added to a blank map using the Add Data button.

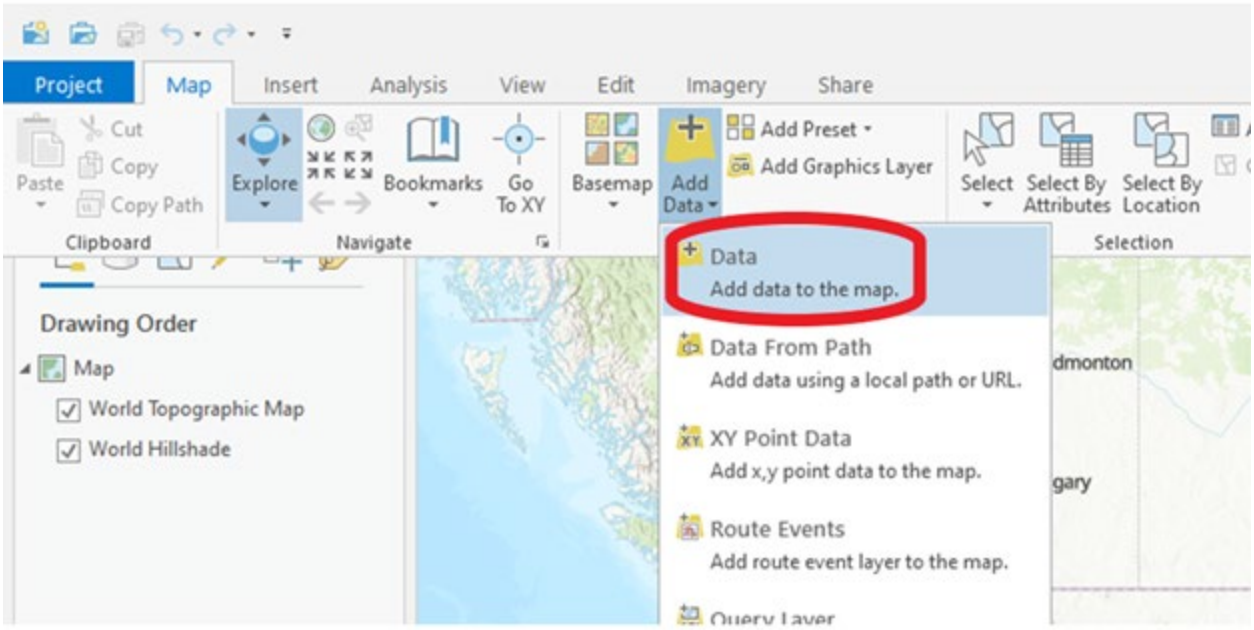



Figure 8: Screenshot of ArcGIS Pro demonstrating how to add data to a map.

- Right click on each feature class within the map's Table of Contents to open the associated attribute table. The attribute table contains the Federal Information Processing Standards (FIPS) code for each county, the county name, and a unique facility name. Each feature class (rmp, proc, and dest) is identical except for the facility names (i.e., Autauga County, Alabama has a facility name of 'rmp_01001' in the rmp feature class, a facility name of 'proc_01001' in the proc feature class, and a facility name of 'dest_010001' in the dest feature class).
- The default facility locations may be sufficient for certain FTOT scenarios, but if not, these feature classes can be used as templates for a custom facility location dataset.

**Building Custom Facility Location Data from the Template in ArcGIS Pro**

- Users who wish to add their own unique facility locations to an FTOT scenario should start with a copy of the default facility location data template feature classes, rather than the original data that is stored in the common_data folder. The template feature classes can be copied into a working directory using Windows Explorer or within ArcGIS Pro using the 'Export Features' tool by right clicking on each feature class and selecting Data-->Export Features to save them into a working directory. Users who wish to only bring a subset of the default facilities into their customized feature class should establish that subset using ArcGIS Pro before exporting with the "select interactively"[1], "Select by Attribute"[2], or "Select by Location"[3] tools.

[1] https://pro.arcgis.com/en/pro-app/latest/help/mapping/navigation/select-features-interactively.htm
[2] https://pro.arcgis.com/en/pro-app/latest/help/mapping/navigation/select-features-using-attributes.htm
[3] https://pro.arcgis.com/en/pro-app/latest/help/mapping/navigation/select-features-by-location.htm

- The new user-created facility location feature classes do not need to have the same names as the template feature classes, but it is best to continue using a unique feature class name for each facility type (raw material producers, processors, and ultimate destinations). Users will need to know the full path to these feature classes so that they can be referenced in the FTOT scenario's XML configuration file.
- Using the Export Features tool will automatically add these new feature classes to the ArcGIS Pro map. If the template data were instead copied using Windows Explorer, make sure to add the newly copied feature classes to the ArcGIS Pro map. The old (original copies) of the feature class can be removed from the map.
- FTOT users who wish to start with a blank template can select all the existing facilities and delete them within an ArcGIS Pro Edit session. For more information on deleting feature classes, consult the ArcGIS Pro documentation.[4] Deleting facilities is optional—users can add facilities without removing existing facilities as long as each added facility has a unique facility name.

**Building Facility Location Data from Scratch using ArcGIS Pro**

- More experienced GIS users can build their own facility location data from scratch (rather than from the template that comes with FTOT). The data must be in a standard GIS data format, each facility type must have its own uniquely named feature class, and each feature class must contain a field called "Facility_Name" (case-sensitive) with a unique identifier for each facility that does not repeat across the FTOT scenario. ArcGIS Pro has documentation on building point feature classes from scratch.[5]

To populate custom facility locations using ArcGIS Pro:

- Under the ArcGIS Pro Map tab, there is a Locate button that can be used to access an interface to help locate facilities based on a name, address, or other identifying information. If this brings up a facility of interest, right click on the result, select Add to Feature Class, and then select the appropriate feature class (rmp, proc, or dest). Press OK. You may need to log in to your ArcGIS account for this functionality to work properly.
- Alternatively, if you've already located where the facility is and you'd like to add a location to your feature class without searching first, navigate to the Edit tab in ArcGIS Pro, select the Create button, and then select the feature class to which you are adding facilities. Ensure that the 'Point' icon is selected and then click on the location on the map where you wish to create a facility. A new facility will be added to the last row in the feature class's attribute table. Open the attribute table and fill in any appropriate fields. As previously mentioned, the only field that must be included is "Facility_Name", but you may wish to create new fields or populate existing fields to include additional information about the facility.

[4] https://pro.arcgis.com/en/pro-app/latest/help/editing/delete-features-and-parts-of-features.htm
[5] https://pro.arcgis.com/en/pro-app/latest/help/editing/create-point-and-multipoint-features.htm

### 3.2.2 Finding Existing Facility Location Data

- Any standard GIS-formatted point feature class (e.g., shapefile, file geodatabase, etc.) is acceptable to generate facilities for FTOT. The key requirements are that:
    - There should be distinct feature classes representing each FTOT facility type (e.g., raw material producers, processors, and ultimate destinations).
    - The feature classes must contain a "Facility_Name" attribute (note: attribute name is case-sensitive) populated with unique facility names for each facility. Facility names cannot repeat across the FTOT scenario. These facility names must be the same facility names represented in the scenario's commodity CSV input files.
- In the likely event that the "Facility_Name" field name is not included with a pre-existing GIS feature class, use ArcGIS Pro to add a new field[6] and then calculate the contents of that new field based on another existing field.[7] Alternatively, rename an existing attribute to "Facility_Name" (case-sensitive) using the "Alter Field" tool.[8]

A few potential facility data sources include:

- U.S. Energy Information Administration Map Data[9]: Contains shapefiles with the locations of biodiesel plants, power plants, and other energy-related facilities.
- Bureau of Transportation Statistics Open Data[10]: Facility location information includes airports, ports, air-to-truck intermodal freight facilities, and other facilities.
- U.S. Environmental Protection Agency Facility Registry Data.[11]

## @@ 3.3 FTOT Supply Chain Data

### 3.3.1 Facility Characteristics Data Input Files

In addition to the XML scenario file and facility location data, FTOT requires a set of comma-separated-values (CSV) files, which define facility-commodity information (e.g., supply/demand amounts, product slates and conversion efficiency, and minimum/maximum facility size, among other elements).

The facility-commodity data are specified in a series of CSV files located within the specific scenario's input_data folder. Three comma-separated-variable input files are available for facility definitions in FTOT. These files contain information for each facility type: raw material producers (RMPs, which are the supply origin locations in the scenario), processors (which are waypoints or processing locations in the supply chain), and destinations (which are locations of demand for the final commodities).

Each facility input file includes the following fields:

[6] https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/add-field.htm
[7] https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/calculate-field.htm
[8] https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/alter-field-properties.htm
[9] https://www.eia.gov/maps/layer_info-m.php
[10] https://data-usdot.opendata.arcgis.com/
[11] https://www.epa.gov/frs/geospatial-data-download-service

- **facility_name**; used to match the facility-commodity data to locations in the scenario geodatabase. NOTE: the facility_name in the input data CSV file must match the records in the Facility_Name field of the GIS feature class. Facility names should be unique and not duplicated. Care should be taken when using county or city names as these are often repeated across states. Additionally, take care that extra trailing whitespace is not included, as "Whitewater" and "Whitewater " will not match.
- **facility_type**; specifies the type of facility (e.g., "raw_material_producer", "processor", "ultimate_destination").
- **commodity**; a unique name for the commodity. FTOT will create origin-destination pairs by matching the commodity names. For example, if an RMP specifies commodity_A as an output and a destination specifies commodity_A as an input, FTOT will try and flow material from the RMP to the Destination. As noted above, care should be taken to avoid extra whitespace in the commodity names. Through these origin-destination pairs, commodity names imply the structure of the supply chain.
- **value**; the quantity of the commodity. Use of this field varies by facility type: for RMPs, it is the maximum available material; for destinations, it is the total demand; for processors, it defines how much output is created by the specified quantity of input. If a processor has more than one input (output) commodity listed, it is assumed that all commodities must be used (produced) in the specified ratio.
- **units**; the units of the quantity for the commodity. Solid commodities must be specified in units of mass; liquid commodities must be specified in units of volume.
- **phase_of_matter**; solid or liquid, (gas is not currently supported).
- **io**; specifies if the commodity is an input (i) into the facility, or an output (o) out of the facility. RMPs by definition ONLY have outputs, and destinations by definition ONLY have inputs. Each processor must have at least one input commodity AND at least one output commodity.
- **schedule** (optional); a user specifies the name of the availability schedule that each facility follows. The schedule name provided in the facility CSV should match one provided in the schedule CSV input file. The amount of product supplied or demanded at the facility on each day of the scenario is equal to the product of the commodity quantity and the fraction availability provided in the schedule.
- **max_transport_distance** (optional); a user-specified maximum transport distance (in miles) that this commodity can travel. This distance should be excluded from scenario runs in which all processors are fully defined for performance reasons. **However, note that this field is required in the Raw Material Producers input CSV file when FTOT is generating candidate processors**.

For processors, there are three additional optional fields:

- **max_processor_input** (optional); here the user can specify the maximum amount of material a processor can take in. This property is often taken from real-world constraints; lower values may drive the optimal solution for the scenario to utilize more processor facilities than just the one on the lowest cost route, resulting in higher transportation costs or even more unmet demand at the destination. If this column exists, it should be the same for all rows of a single processor,

not different by commodity. If this column does not exist, processor capacity is unbounded. The max_processor_input field can be left blank for some or all processors; these processors will have no restriction on the amount of material they process, though the processing ratio is still defined by the "value" field.

- **min_processor_input** (optional); here the user can specify the minimum amount of material a processor can take in if it is utilized. If this column exists, it should be the same for all rows of a single processor, not different by commodity. If this column does not exist, minimum processing capacity defaults to one-half the maximum. The min_processor_input field can be left blank for some or all processors.
- **build_cost** (optional); to indicate that a processor is a candidate facility as opposed to an existing facility, the user must add the build_cost field in the processor commodity input file and specify a positive fixed build cost. Processors for which this field is 0 or missing are considered existing facilities. To use the optional build_cost field, the user should enter numbers representing the amortized cost of building the facility across the given time period. If this column exists, it should be the same for all rows of a single processor. Note that this is a separate functionality from candidate generation, which is specified in Section 3.3.3.

Processor facility input files are also able to specify conversions with multiple input commodities and multiple output commodities. For example, in cases where the processor requires two inputs (e.g., blueberries and sugar) and one output/product (e.g., jam), the two raw materials are specified as inputs to the same processor, and the output can be specified as a ratio of the two inputs. Minimum processor input and maximum processor input parameters apply across input commodities. If multiple input commodities are specified for a processor, their quantities **must** be provided in the same units if minimum processor input and/or maximum processor input are used. Note that FTOT requires all input commodities to be available in order to generate the outputs. FTOT will not use the facility if one commodity is missing. If one of the input commodities is limited, then FTOT will generate up to the limiting amount of input material.

### 3.3.2 Commodity Mode Input File

This optional input file allows the user to toggle different modes on and off for individual commodities. Users can also assign specific truck, railcar, or barge types to a commodity. This CSV file can be stored in the same place as the other scenario input data, for example the facility commodity CSV files, are stored.

The file name and file path should be added to the `Commodity_Mode_Data` element in the scenario XML.

<Commodity_Mode_Data>YOUR_SCENARIO_FOLDER_HERE\commodity_mode.csv</Commodity_Mode_Data>

The commodity mode CSV file must be included in order to include pipelines in the solution. Both a crude pipeline network and a product pipeline network are included in the FTOT network but disabled for all commodities by default. This is to allow users to have flexibility in naming commodities while

preventing commodities that are not supposed to flow on pipeline from utilizing it in the optimal scenario since it is usually the least expensive mode. In modeling real-world scenarios, the user should note that most commodities are not allowed to flow on both the crude and product pipeline networks, though these commodity-mode decisions are left up to the user as best fit their scenario.

As depicted below in Table 1, users can input a Y for yes or an N for no within the CSV file to toggle a mode on or off for a commodity. Commodity-mode pairs with a Y are assigned the default vehicle type for that mode as defined in the scenario XML file. Users can alternatively specify a vehicle label selected from the 'vehicle_types.csv' file in the 'lib' folder of the project code repository (e.g., C:\FTOT\program\lib) to permit travel via a custom vehicle. Changing the vehicle type for a commodity updates the post-processing and reporting for that commodity and mode but does not affect the optimization.

**Table 1: commodity_mode.csv for two commodities: crude oil, and a generic petroleum product (pet_prods).**

| commodity | road | rail | water | pipeline_crude | pipeline_prod |
|---|---|---|---|---|---|
| crude_oil | N | Y | Y | Y | N |
| pet_prods | small_truck | Y | Y | N | Y |

By default, FTOT comes with a small_truck option pre-populated in vehicle_types.csv. This truck type represents a single-unit truck and can be assigned in the commodity mode input file as a ready-to-use option for commodities traveling on road. The vehicle_types.csv structure and small_truck attributes are presented below in Table 2. The small_truck vehicle includes a row with the element and value for each road-related payload, fuel efficiency, and $CO_2$ emissions entry in the XML file. Vehicle cost is not included since only the default vehicle defined in the scenario XML file is used for the optimization.

In Table 1, crude oil is only allowed to flow on the crude pipeline network (pipeline_crude), and not allowed in the petroleum products pipeline (pipeline_prod). Similarly, the generic petroleum product (pet_prods, e.g., gasoline, diesel, jet fuel) commodity is not allowed to flow on the pipeline_crude network but is allowed to flow on the pipeline_prod network. Additionally, crude_oil travels by road using the default truck defined in the scenario XML file while pet_prods travels on small_truck as specified in vehicle_types.csv.

**Table 2: vehicle_types.csv with the pre-populated small_truck vehicle for road.**

| vehicle_label | mode | vehicle_property | value |
|---|---|---|---|
| small_truck | road | Truck_Load_Solid | 8 tonne |
| small_truck | road | Truck_Load_Liquid | 2.5 kgal |
| small_truck | road | Truck_Fuel_Efficiency | 12.1 mi/gal |
| small_truck | road | Atmos_CO2_Urban_Unrestricted | 1093.19 g/mi |
| small_truck | road | Atmos_CO2_Urban_Restricted | 894.60 g/mi |
| small_truck | road | Atmos_CO2_Rural_Unrestricted | 913.71 g/mi |
| small_truck | road | Atmos_CO2_Rural_Restricted | 886.37 g/mi |

Users can also edit the vehicle_types.csv file to create custom vehicles for the road, rail, and water modes. When adding a custom vehicle to vehicle_types.csv make sure to include all solid payload, liquid payload, fuel efficiency, and $CO_2$ emissions elements for the corresponding mode as specified in the scenario XML file.

### 3.3.3 Candidate Generation Option

FTOT can generate screening-level processor candidate locations to convert raw material to commodities demanded by the destinations. Candidate generation requires the user to specify the input and output commodity relationship, as well as the facility maximum and minimum size, minimum aggregation size for generating a candidate processor, and the amortized capital cost as a function of size. Currently, FTOT does not allow candidate generation for supply chain scenarios with multiple processor steps.

- In order to run a candidate generation scenario, the user must add the max_transport_distance field in the RMP commodity input file. This field is mandatory for FTOT runs with candidate generation.
- A new facility-commodity CSV file is used in this scenario: proc_cand.csv. It contains six attributes per type of processor, listed as six rows in the CSV file: one for the input commodity and one for the output commodity, as usual, plus minimum and maximum facility sizes (minsize and maxsize, respectively), minimum amount of material aggregation on the network to place a candidate facility (min_aggregation) and cost_formula. The relationship between input and output commodities is stored in FTOT per unit of input material. Therefore, the user is free to use whatever commodity values are convenient for them, as long as the ratio is correct. All six attributes are required inputs except for min_aggregation; if min_aggregation is left blank, it defaults to one-fourth the minsize.
- The candidate processor size is limited by the minsize and maxsize parameters. The minsize of the facility is the minimum amount of material that must flow through the facility during the optimization for FTOT to utilize it as a candidate. The maxsize is the largest size facility (defined by input commodity) that FTOT will generate. The max_processor_input field will be populated with this maxsize value when the ftot_generated_processor_candidates.csv file is generated as an intermediate output file by FTOT. The min_aggregation is the quantity of material that must flow over a given link on the network to generate a candidate node.
- The cost formula defines the amortized capital cost for candidate processors. This is specified as a formula in units of dollars per input material amount, with the maxsize value used as the processor capacity.
- FTOT identifies candidate nodes where sufficient raw material is aggregated on the network to support a potential facility within the maximum transport distance.

In the first step of the candidate generation process, FTOT identifies a set of candidate processors based on the minimum aggregation heuristic. A candidate processors feature class is generated in the scenario GDB, and an FTOT-generated candidate processors facility-commodity CSV file (e.g., ftot_generated_processor_candidates.csv) is stored in the .\debug folder.

FTOT now processes the new facilities in the same fashion as other known locations. It will rerun the facility, connectivity, and graph steps (this time with the number 2 for logging purposes, e.g., f2, c2, g2). The candidate processors are added into the list of all processors considered by FTOT during the supply chain optimization. At this point, the scenario is functionally the same as in scenarios where existing / known processor candidates are used.

### 3.3.4 User-Provided Candidate Processor Option in Optimizer

FTOT can evaluate user-defined candidate processors in addition to FTOT-generated candidates. In order to use candidate processors not generated by FTOT (e.g., identified by a siting tool), the user will need to execute the following steps:

- Specify candidate processor locations in the processor feature class layer within their facilities gdb file. The feature class includes the 'Facility_Name' field, which is a unique identifier for each facility that matches with the facility-commodity CSV file.
- Provide user-provided candidate processors in the "Processors_Commodity_Data" CSV file named "proc.csv". In order to indicate that a processor is a candidate facility as opposed to an existing facility, the user must add the build_cost field in the processor commodity input file and specify a **positive** fixed build cost. Processors for which this field is 0 or missing are considered existing facilities. To use the optional build_cost field, the user should enter numbers representing the amortized cost of building the facility across the given time period. This cost should be included on all rows for a candidate processor; it will only be counted once.
- Set the max_transport_distance field in the RMP commodity input file.

These facilities are added to the main.db and main.gdb just as the known and existing RMPs, Processors, and Destinations are. If by chance a candidate processor generated in the OC step is also an externally-generated candidate processor (e.g., build_cost > 0 in proc.csv), then the build cost from proc.csv is used.

# @@ 4 ADVANCED SCENARIO OPTIONS

## 4.1 Customizing the FTOT GIS Network

After installing FTOT, the default multimodal network utilized in FTOT is available for download with all the other supporting data and quick start scenarios on the FTOT GitHub site. The feature classes included with the network are shown in Figure 9 and are available in the scenarios/common_data/networks subdirectory. Full metadata for the multimodal network can be accessed in ArcGIS Pro. Additional technical discussion of the FTOT GIS Network is provided in Section 2.2 of the FTOT Technical Documentation.

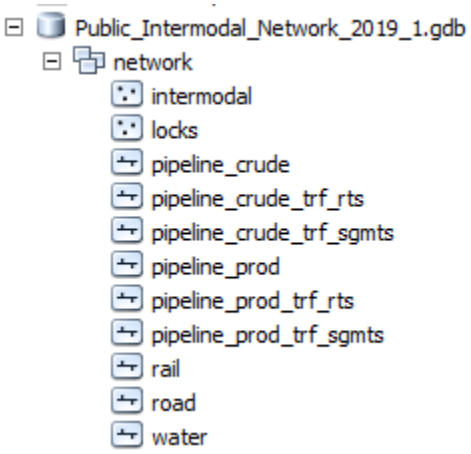



**Figure 9: Default multimodal network feature classes included in base FTOT network.**

For most FTOT scenarios, users should utilize the default multimodal GIS network. Due to the complexity of the underlying multimodal GIS network structure, FTOT does not currently support using other networks. The key limitations are the fact that the network currently requires certain attributes (some of which are not easily available in other networks) and must be fully connected and flowable—including the existence of artificial links that connect the network segments to intermodal facilities.

In some circumstances, an FTOT user may wish to customize the existing default FTOT multimodal network. For example, a user may wish to add an additional network segment (or handful of new network segments) to the network. This is achievable provided the FTOT user has some existing GIS experience and the patience to customize the GIS layers provided by FTOT, as the process is not automated. Adding network segments is not recommended if the user intends to add more than a dozen or so additional network segments, due to the complexity of integrating new data into an existing network. Section 4.1.1 walks through this process in detail.

In addition, segments can be automatically removed from the default FTOT network (i.e., 'disrupted') through the creation of an optional disruption data csv. The process for this is described in Section 4.1.2.

### 4.1.1 Adding Segments to the FTOT Network

Adding segments to the existing default FTOT Multimodal Network may be useful in scenarios in which a key link is missing from the default FTOT network, or if you wish to include a proposed or under construction link in your analysis.

Note that for pipeline, the process is somewhat more complicated—feel free to skip the **PIPELINE NOTE ONLY** sections if adding segments to other modes in the FTOT network (road, rail, and water).

1. Make a copy of the default FTOT multimodal network geodatabase (e.g., C:/FTOT/scenarios/common_data/networks/Public_Intermodal_Network_2010_3.gdb). You can save it the same directory, but make sure to rename it to distinguish it from the default network.
2. Open your GIS software of choice (e.g., ArcGIS Pro) and navigate to the copy you just made of the network geodatabase. Identify the mode for which you wish to add additional network segments (road, rail, water, crude pipeline, or petroleum product pipeline). If not pipeline, finding the right feature class to modify is simple—choose the 'road', 'rail' or 'water' feature class and add it to an existing map. If pipeline, read the following note.

**PIPELINE NOTE ONLY:** There are three pipeline feature classes provided for both crude oil and petroleum products. The reason for the added complexity is due to the unique nature of the pipeline network—unlike the other modes, FTOT limits possible movements along the pipeline to known origin-destination pairs for which tariffs have been designated and does not allow commodities to flow freely on or off the network as it does for other modes. To help enforce that restriction, FTOT utilizes three different feature classes for each commodity. Section 2 of the main FTOT documentation provides a brief description of how each feature class differs. Once you determine the commodity you are utilizing (crude or petroleum product), you should focus on the feature class ending in "trf_rts". The FTOT team currently does not support the modification of the other two pairs of feature classes (pipeline_crude and pipeline_crude_trf_sgmts / pipeline_prod and pipeline_prod_trf_sgmnts), which are only utilized in capacity-constrained scenarios. As a result, we only recommend adding additional pipeline movements to the FTOT network in scenarios where the capacity constraint and background flows are disabled.

3. Once you have opened your desired network mode's GIS feature class, use your GIS functionality to digitize new segments where necessary. When adding new segments, use your GIS to draw a new connection between an origin and destination. For guidance on creating polyline features in ArcGIS Pro, refer to the ArcGIS Pro documentation.[12] For road, rail, and water, ensure that any new segments are snapped into the existing network.[13] You will also need to split the existing network at any new junctions in the network that are made.[14] If you do not split existing segments where your new segments intersect the existing network, they will

[12] https://pro.arcgis.com/en/pro-app/latest/help/editing/create-polyline-features.htm
[13] https://pro.arcgis.com/en/pro-app/latest/help/editing/snap-while-creating-geometry.htm
[14] https://pro.arcgis.com/en/pro-app/latest/help/editing/split-a-feature.htm

be unreachable from the rest of the network. In most cases, this prevents them from being utilized in FTOT scenarios.

**PIPELINE NOTE ONLY:** Make sure to start drawing at the origin and end at the destination of a particular pipeline movement—the order matters, as two-way movements along pipelines are not allowed as is the case for the other modes.

4. Once you have completed generating your new feature geometry, you will need to specify the new feature attributes.

For road, attributes that must be populated include:

- FCLASS (Functional Class)—using the FHWA approved Functional Classification System.[15]
- URBAN_CODE (U.S. Census Urban Area Code).[16] When in doubt, utilize the same urban code that is entered for existing road segments in the surrounding area. This attribute is necessary to determine whether the roadway is classified as urban or rural, which impacts emissions reporting.
- Artificial—should be set to 0 for all added segments.
- MODE_TYPE—should be set to 'road'.
- MILES—select any new or modified road segments (including any segments that you split in order to connect in new road segments) and use the Calculate Geometry[17] tool to calculate the mileage of each road segment.
- Additionally, volume, capacity, and VCR (volume capacity ratio) must be populated if capacity or background flows are enabled. Volume and capacity must be entered in terms of vehicles per day and volume capacity ratio simply needs to be entered as volume divided by capacity.
- All other attributes are optional.

For rail, attributes that must be populated include:

- Density_Code: Valid values include any number from 3 to 7. A higher number within this range means FTOT will prioritize flows over lower numbers with mileage being equal. Density codes for the public network are based on the following rules:
    - Density Code 7—STRACNET (Strategic Rail Corridor Network)- Class 1 Ownership
    - Density Code 6—Other STRACNET (non-Class 1 Ownership)
    - Density Code 5—Class 1 Ownership (non-STRACNET)
    - Density Code 4—Class 1 Rights (non-STRACNET)
    - Density Code 3—Non-Class 1 (non-STRACNET)
- Artificial—should be set to 0 for all added segments.
- MODE_TYPE—should be set to 'rail'.

[15] https://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/page04.cfm#toc249159687
[16] https://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/page04.cfm#toc248828519
[17] https://pro.arcgis.com/en/pro-app/latest/tool-reference/data-management/calculate-geometry-attributes.htm

- MILES—select any new or modified rail segments (including any segments that you split in order to connect in new rail segments) and use the Calculate Geometry[18] tool to calculate the mileage of each rail segment.
- Additionally, capacity must be populated if you plan to use the network for capacitated scenarios. Capacity must be entered in terms of train cars per day. The public FTOT network does not have background flow data available— therefore, the volume and VCR fields for new segments can be left blank.
- All other attributes are optional.

For water, attributes that must be populated include:

- TOT_UP_DWN (the tonnage of any freight that flows on the segment)— this data is populated in other segments by the USACE National Waterway Network and can be estimated or based on nearby segments.
- Artificial—should be set to 0 for all added segments.
- MODE_TYPE—should be set to 'water'.
- MILES—select any new or modified water segments (including any segments that you split in order to connect in new water segments) and use the Calculate Geometry[19] tool to calculate the mileage of each water segment.
- All other attributes are optional.

For pipeline, attributes that must be populated include:

- Base_Rate (this is the cost to flow this particular movement in cents per barrel)
- Tariff_ID (sequential unique number— use any number that is not already used)
- Artificial—should be set to 0 for all added segments.
- Commodity ('Crude Oil' or 'Petroleum Products' depending on the commodity)
- MODE_TYPE—should be set to 'pipeline_crude_trf_rts' or 'pipeline_prod_trf_rts' depending on the commodity.
- MILES—select any new or modified pipeline segments (including any segments that you split in order to connect in new pipeline segments) and use the Calculate Geometry[20] tool to calculate the mileage of each pipeline segment.
- All other attributes are optional.

Following Steps 1-4 above will allow scenarios to utilize these new segments— except in cases where these new segments need to be directly connected to existing intermodal facilities (e.g., to allow for multimodal movements). For enabling multimodal movements with these new segments, continue on with steps 5-6 below. Otherwise, skip to Step 7.

[18] Ibid.
[19] Ibid.
[20] Ibid.

5. In some cases, particularly in situations where you have added new pipeline tariffs, you may need to add additional intermodal facilities to the network. Open your custom network's 'intermodal' feature class. The easiest method is to add intermodal facilities at the new segment's start or end points— this eliminates the need to digitize artificial links to connect the new segments to the new intermodal facilities. You can use GIS functionality to 'snap' these points to exactly the start and end points of the segment(s) that were added. Modify the attributes of these new intermodal facilities off of the attributes provided for the other intermodal facilities. The essential columns to populate for each new intermodal facility are to populate "Y" for any modes that the intermodal facility is supposed to connect to.
6. Artificial links will need to be manually added to connect any other relevant modes to these new intermodal facilities. This involves opening the relevant mode feature class and tracing new connections between the intermodal facility and the mode's closest existing segment. It is easiest to trace these connectors so they connect into existing nodes (intersections) in the mode's network. Otherwise, you will have to split the existing network at these new nodes to ensure that the artificial links are actually accessible from the rest of the mode's network. The Split tool[21] can help with that functionality in ArcGIS Pro. If you do split features in the existing network, you'll need to recalculate the "MILES" field with updated mileage. Once the new artificial segment is digitized, assign each new artificial link an "Artificial" attribute of 1 and a MODE_TYPE consistent with the other features in the layer (e.g., 'road' for the road feature class). Also, calculate the MILES of the new segment using "Calculate Geometry". Other attributes can be left blank.
7. Modify your scenario files accordingly to reference your new network. You are now ready to run scenarios using the network.

### 4.1.2 Disruption Data

The user can populate an optional disruption data CSV in order to disrupt (i.e., make unavailable) certain segments in the input FTOT multimodal network. The CSV consists of three columns in which the mode, unique link ID, and level of link availability is identified for each segment of interest. The specific schema for the disruption data CSV can be found in Reference Scenario 4 (Disruption). The first three columns must consist of "mode", "unique_link_id" (which refers to the OBJECTID associated with each network link in the corresponding GIS feature class) and "link_availability". Only segments that will be disrupted need to be included in this CSV. Segments not included in the table will not be disrupted. To identify the segment IDs to be disrupted, the user will need to open up the input FTOT network in GIS software and identify the segment IDs manually. There is an FTOT Supporting Tool (see Section 7.3) that can help with this process if appropriate input data are available.

At this time, only a link availability of 0 (fully disrupted) in the disruption data CSV is recognized by FTOT. In these cases, the links will be completely removed from the network and unavailable for any optimal solutions. This is useful in cases when the user would like to model a scenario in which a certain

[21] https://pro.arcgis.com/en/pro-app/2.8/help/editing/split-a-feature.htm

segment or corridor is unavailable due to some sort of hazard (e.g., flooding, earthquake) or other form of disruption (construction, motor vehicle crash).

## 4.2 Schedule Input File

Schedules can be used to run scenarios that span multiple time steps (the default and recommended time step is in days). This optional input file allows the user to define schedules of facility availability for each day in a scenario. An availability of 1 indicates that the facility produces or demands the same amount of the commodity as in the "quantity" column of the facility input file. An availability of 0 indicates the facility does not produce or demand any product on that day, and an availability of 1.5 indicates the facility produces or demands 1.5 times the amount in the "quantity" column in the facility input file.

The schedule input file includes three columns: schedule, day, and availability. Each schedule's default value is indicated by day '0' and any days with a different availability must be specified. All schedules for a scenario are the same length. The scenario schedule length is determined by the highest value in the 'day' column. FTOT forces all schedules for a scenario to be the same length to avoid mismatch issues between facilities with schedules of different lengths. An example of a schedule input is shown in Table 3.

**Table 3: Example of schedule input file containing two 7-day schedules.**

| schedule | day | availability |
|---|---|---|
| weekdays | 0 | 1 |
| weekdays | 1 | 0.5 |
| weekdays | 7 | 0.5 |
| exceptDay3 | 0 | 1 |
| exceptDay3 | 3 | 0 |

The table has two schedules. The 'weekdays' schedule has an availability of 0.5 on days 1 and 7 and availability of 1 on days 2 through 6. Since the largest value in the day column is 7, that is the scenario schedule length. As a result, the exceptDay3 schedule is also 7 days long even though only the default value, and day 3 value are specified. The 'exceptDay3' schedule has an availability of 0 on day 3 and an availability of 1 on days 1-2 and 4-7. Reference Scenario 3 provides an example schedule file.

The file name and file path should be added to `Schedule_Data` element in the scenario XML.

## 4.3 Customizing Emissions Outputs

### 4.3.1 Commodity Density Input File

This optional input file allows the user to specify each commodity's density. Currently, density values are used only for calculating emissions from the transport of liquid commodities on rail, water, and pipeline modes. This CSV file is optional and can be stored in the same place as the other scenario input CSV files.

Once this CSV file is stored, the user-specified file name and file path should be added to the `Commodity_Density_Data` element in the scenario XML:

<Commodity_Density_Data>YOUR_SCENARIO_FOLDER_HERE\commodity_density.csv</Commodity_Density_Data>

The commodity density CSV is structured as in Table 4, with the first column titled "commodity" containing a commodity's name and the second column titled "density" containing a string with a density value and units, expressed as a unit of mass per unit of volume. FTOT will automatically process and convert the density to the necessary units for the emissions calculation.

**Table 4: commodity density CSV for two example commodities: ethanol and water.**

| commodity | density |
|---|---|
| ethanol | 0.79 kg/liter |
| water | 1.0 g/cm^3 |

Densities for solid commodities or unrecognized commodity names are accepted (no error is flagged) but disregarded. The default density specified in the scenario XML's `Density_Conversion_Factor` parameter will be assigned to any liquid commodity not included in the commodity density CSV.

### 4.3.2 Non-$CO_2$ Emission Factors Input File

Carbon dioxide emissions are calculated by FTOT by default for the optimal solution. If the user would like to calculate non-CO2 emissions from the transportation associated with the optimal scenario, the detailed_emission_factors.csv file is located in the 'lib' folder of the project code repository (C:\FTOT\Program\lib) and is downloaded automatically with FTOT. FTOT uses the data in this file to calculate non-$CO_2$ emissions by commodity and mode. Users can set the `Detailed_Emissions_Factors` element in the scenario XML to True to output non-$CO_2$ emissions in a separate report file.

The detailed_emission_factors.csv file is prepopulated with emissions data for FTOT's default vehicles for transport on road, rail, and water modes as well as for the "small_truck" that is provided in vehicle_types.csv. The default emission factors will be used for all commodities on a mode *except* in the case that a custom vehicle is assigned to a commodity (see Section 3.3.2). If users create a new custom vehicle, they will need to (1) assign that vehicle to a commodity and (2) add custom emission factors to detailed_emission_factors.csv to include that vehicle in the detailed emissions report.

The detailed_emission_factors.csv file contains the following fields:

- vehicle_label – set to "Default" for the default vehicles assigned in the scenario XML. You can alternatively enter a vehicle label that matches the name of a custom vehicle in vehicle_types.csv. Note: The vehicle label is case-sensitive.
- mode – set to road, water, or rail.

- road_type – set to “NA” for water or rail. For road, set to “Rural_Restricted”, “Rural_Unrestricted”, “Urban_Restricted”, or “Urban_Unrestricted”. Note: The road type is case-sensitive.
- Pollutant – can be set to one of the following values: CO, CO2e, CH4, N2O, PM10, PM2.5, VOC.
- Value – the emission factor for this entry. Include units of g/mi for road entries and g/ton/mile (or other unit of mass besides ton) for rail and water.

The vehicle emissions portion of Section 3.10 of the Technical Documentation provides additional information on the prepopulated pollutant emissions factors.

# @@ 5 RUNNING A SCENARIO

## 5.1 FTOT Scenario Sequence

FTOT is a command line tool that runs in a sequence of steps. Each component of an FTOT run represents a generalized step within the scenario that the user can review in corresponding log files generated during each step. Each component in this sequence can be run as part of a full FTOT run (this is applicable to most users' scenarios) or in isolation (for debugging or advanced FTOT scenario testing). The basic FTOT sequence for a standard scenario is:

1. S – setup; prepare the scenario files and transportation network
2. F – add the facility GIS and facility-commodity data to the scenario files
3. C – connect the facilities to the transportation network
4. G – export a NetworkX graph for the optimization
5. O1 – prepare the optimization problem
6. O2 – setup and solve the optimization problem
7. P – post process the optimal solution
8. D – generate reports for the run
9. M – generate maps of the run

For candidate processor generation scenarios, several additional steps (highlighted in **bold**) are run during the FTOT sequence:

1. S – setup; prepare the scenario files and transportation network
2. F – add the facility GIS and facility-commodity data to the scenario files
3. C – connect the facilities to the transportation network
4. G – export a NetworkX graph for the optimization
5. **OC – pre-candidate generation optimization**
6. **F2 – add generated facility locations and commodity data to the scenario (specified as F2 to distinguish from pre-defined processor facilities)**
7. **C2 – connect the new facilities to the transportation network**
8. **G2 – export a new NetworkX graph for the optimization**
9. O1 – prepare the optimization problem
10. O2 – setup and solve the optimization problem
11. P – post process the optimal solution
12. D – generate reports for the run
13. M – generate maps of the run

Further details on candidate generation can be found in Section 3.3.3.

## 5.2 Batch (BAT) File

Each scenario contains a batch file called **run_vX_X.bat (current version is run_v6_1.bat)**. A batch file is used to automatically run the sequence of steps necessary for a complete an FTOT scenario. An advanced user can also manually modify the batch file to only run certain steps necessary for testing or debugging purposes. The batch file references the scenario XML configuration file, which is loaded at runtime during each step. The file also references the Python path and FTOT directory. If a user has

based their scenario off an existing quick start or reference scenario, they must modify the batch file ahead of running their own customized scenario.

- `set XMLSCENARIO={}` - Replace existing path inside brackets with full file path to the new scenario XML file.
- NOTE: If you have stored your FTOT installation anywhere other than “C:\FTOT” or your FTOT Python environment anywhere other than “C:\FTOT\python3_env” (these are the defaults as defined in the FTOT installation instructions), then you will also need to modify these paths for each batch script that you run to appropriately reflect the actual paths on your machine.

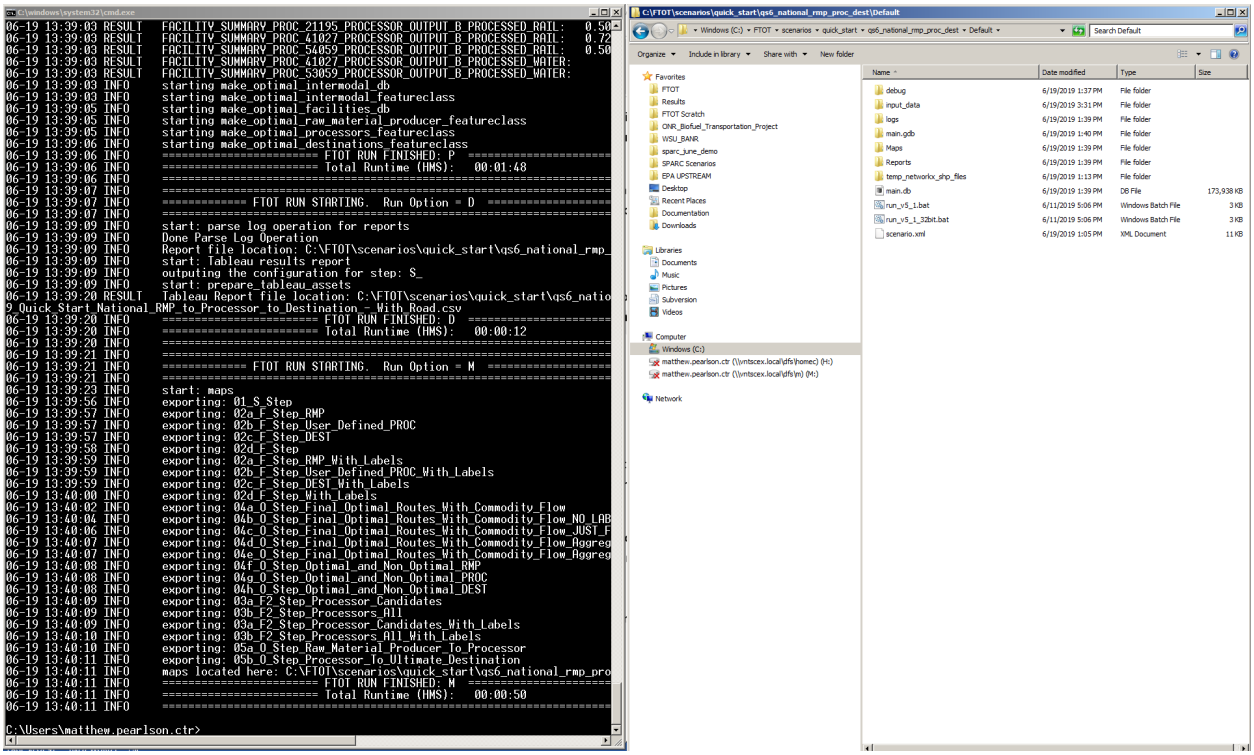



**Figure 10: Split screen practice for running an FTOT scenario. The command line is on the left, and the scenario opened in the Windows Explorer is on the right.**

## 5.3 FTOT Scenario Execution

FTOT is a command line program that executes in the Windows shell. It is a recommended practice to run the scenarios with a command line window on the left, and the scenario folder opened in an explorer window on the right. This will allow the user to see that the scenario running in the appropriate folder.

A scenario can be started by dragging the batch file located in the scenario folder into the command line and hitting the [enter] key. Alternatively, you can run the batch script by double clicking it. During the run, information is logged to the command line providing progress information and results for each step.

Detailed log files are created for each step and timestamped in the .\logs folder. As new files are created in the various FTOT steps, they will become visible in the explorer window on the right.

Informational logging is available in the command shell during the run. Detailed logging is available in the **.\logs** folder. The logs are prefixed with a letter and suffixed with a timestamp indicating the FTOT step and time the log was generated. The user is encouraged to read the logs to familiarize themselves with the FTOT operations occurring during each step.

See the troubleshooting guide in Section 8 for tips on how to resolve common issues like runtime dependency errors (missing software), missing input data, and missing base maps.

# @@ 6 ANALYZING A SCENARIO

## 6.1 Results

FTOT generates four main types of outputs described in detail below. Three different sets of reporting outputs (items 1-3) are generated in the D Step and maps (item 4) are generated by the M step.

1) **A human-readable text report (.txt)** shows a summary of the results for each step in the analysis. The report is broken into the following sections: run time summary of each step, intermediate calculations and optimal results, configurations, warnings, and errors. This is saved in the **.\Reports** directory of the scenario.
2) **A CSV file report (.csv)** that can be used to generate graphical dashboards showing summary map and statistics for the scenario, such as relative contributions of commodities and mode to cost, emissions, and vehicle-miles traveled (VMT), amount of supply utilized and demand met in the scenario, and other elements. The CSV file can be used as an input to Excel, Tableau, or other data analysis programs. This is saved in the **.\Reports** directory of the scenario. The CSV report includes multiple groups of results: the scenario configuration, the commodity-specific summary results, the facility summary results, and the scenario summary results.
    a. The scenario configuration reports out the scenario name, description, and various input parameters from the XML, as well as the name and location of the GIS layers used to define the network and the facilities included in the scenario.
    b. The commodity summary results include the following data by commodity and mode:
        i. Mass and volume movements
        ii. Cost of movements
        iii. Fuel burn
        iv. Miles of the network used in the solution
        v. Vehicles
        vi. VMT
        vii. $CO_2$
    c. The facility summary results include
        i. Facility utilization (amount of supply utilized or demand met)
        ii. Facility utilization fraction (relative to total supply or demand)
    d. The scenario summary results include the following data by mode (aggregated across commodities):
        i. Cost of movements
        ii. Fuel burn
        iii. Miles of the network used in the solution
        iv. Vehicles
        v. VMT
        vi. $CO_2$

3) **A packaged Tableau workbook (.twbx)** that contains all the geospatial and summary result information required to display a Tableau dashboard in the free version of the Tableau Reader software. This is saved in the **.\Reports** directory of the scenario.
4) **Maps** from each step of the analysis, including the network, facilities, candidate processing locations, and the optimal solution (optimal facilities, optimal flows, non-optimal facilities, etc.) are saved in the **.\Maps** directory of the scenario. FTOT generates a series of maps for each FTOT step to help the user see what happens during the scenario.

Supplementary reports on the scenario results are also generated alongside the other main outputs in the **.\Reports** folder:

- Artificial links – the artificial_links_TIMESTAMP.csv output file summarizes the artificial links used to connect facilities to the multimodal network. Each row of the file specifies a facility (e.g., RMP, proc, or dest) in the scenario. A column is written for each permitted mode in the scenario. Each entry in the table is the artificial link length (in miles) if the facility is successfully connected to that mode, or "NA" if the facility is unable to connect to that mode with the artificial link distance parameter specified in the scenario XML file. Note that stranded facilities (those that fail to connect to the multimodal network at all) are not included in the artificial links CSV file.
- Optimal routes - when network density reduction is enabled to calculate shortest paths (see Section 3.3), an additional optimal_routes_TIMESTAMP.csv file is generated containing information on routes used in the optimal solution. The user is free to create their own analysis or tools for reviewing these data.
- Non-$CO_2$ emissions – when detailed emissions reporting is enabled, the detailed_emissions_TIMESTAMP.csv report is generated with total emissions for several non-$CO_2$ compounds. Emissions are reported by commodity, mode, and pollutant.

Reports and maps are stored in timestamped folders within their respective directories and are re-generated (not overwritten) after each successful run. Beyond the reports and maps, the full set of FTOT results are stored in a SQLite database (main.db) and geospatial data underlying the maps are stored in the scenario geodatabase (main.gdb). Both of these datasets are saved in the scenario's main directory. These datasets are overwritten for each successful run.

### 6.1.1 Understanding Costs Reported by FTOT

Of particular note when interpreting FTOT reporting are the various types of costs associated with a scenario. There are three main costs reported by FTOT for the optimal solution:

1) Dollar Cost—the actual dollar cost of the transportation flows in the optimal solution based on the modal costs. For road, rail, and water modes, these are per-mile costs that are constant across the entire network. For example, the dollar cost of travel on one mile of a local roadway is identical to the dollar cost of travel on one mile of interstate highway. These costs are defined in the scenario XML. Intermodal movements are assigned a unit-based transloading cost which

is also defined in the scenario XML. As noted below, in the routing, these dollar costs are adjusted based on weights and other factors; therefore, the route with the lowest dollar cost is not always chosen as the optimal route.

2) Routing Cost—Similar to dollar cost but adjusted by weights based on network link attributes to encourage flows on major links (e.g., interstate highways). The routing cost of traveling one mile on an interstate highway is less expensive than the routing cost of traveling one mile on a local roadway, so optimal routes tend to gravitate towards these major corridors, even if this leads to marginally higher dollar costs (longer distances). FTOT will always select optimal routes that lead to the lowest routing cost, irrespective of dollar cost. Due to the use of weight multipliers (defined in the scenario XML), routing cost will always be greater than or equal to the dollar cost. Users should also note that short haul penalties which encourage FTOT to avoid unrealistically short rail and water movements also only impact routing cost (not dollar cost).
3) Optimal Objective Value (Total Routing Cost + Unmet Demand Penalty + Amortized Cost of Constructing New Candidate Processors)—this is the full cost that the optimizer considers to choose the optimal route. In many FTOT scenarios, the routing cost is the only contribution to the optimal objective value if no candidate processors with build costs are used and all of the demand at the destination was met.

### 6.1.2 Interpreting Flows

The FTOT-generated Tableau workbook and maps help visualize flows within an FTOT scenario. Advanced users can also use the raw GIS data provided in the main.gdb to generate customized maps, if desired. Additionally, if network density reduction is enabled, shortest path routing information is stored in the SQLite database in the route_edges and od_pairs tables; this route data can be combined with optimal routes CSV file to fully characterize flows in the optimal solution.

The remainder of Section 6 of this User Guide goes into more detail in how to interpret the Tableau workbook and map outputs.

### 6.1.3 Emissions

The FTOT reports and Tableau dashboard include total $CO_2$ generated from transport. This value is $CO_2$ generated from end use combustion only, i.e., from fuel burned by the vehicle. Total $CO_2$ from movements on road depends on vehicle miles traveled while total $CO_2$ from movements via rail, water, and pipeline depend on both vehicle miles traveled and commodity weight. In addition, commodity density is used in the total $CO_2$ calculation for liquid commodities on non-road modes. The optional detailed emissions report presents similar information for non-$CO_2$ emissions, specifically carbon monoxide (CO), methane ($CH_4$), nitrogen dioxide ($N_2O$), particulate matter (PM10 and PM2.5), volatile organic compounds (VOCs), and carbon dioxide equivalent ($CO_2e$).

## 6.2 Graphics Dashboard

FTOT outputs include a packaged Tableau workbook (.twbx file) to visualize the CSV report results and the facilities and routes from the analysis. The workbook includes a Tableau "story" with dashboards presenting facility-level, commodity-level, and mode-level results as well as information on quantities of material moved, utilization levels, $CO_2$, VMT, mileage, fuel burn, and costs.

To view the Tableau story, navigate to the reports sub-directory in the scenario folder and select the latest report folder. Double click on the tableau_dashboard.twbx file to open it in Tableau Reader. Note you will need to have Tableau Desktop or Tableau Reader installed.

### 6.2.1 FTOT Tableau Dashboard Features

At the top of the workbook are navigation buttons to bring the user to the various dashboards within the scenario story. The story includes five dashboards:

1. Supply Chain Summary includes a map and data chart with user inputs on facility locations and available supply and demand.
2. By Commodity & Mode includes a map with the optimal routes and a graph pane presenting key scenario measures from the optimal solution, such as dollar cost, vehicle miles traveled, and $CO_2$, emissions.
3. By Supply & Demand includes a map and graph pane presenting facility utilization under the optimal solution.
4. Runtimes displays the time used to run each FTOT step.
5. Parameters Table lists input values from the scenario XML.

**Dashboard functionality**

The three dashboards with maps (Supply Chain Summary, By Commodity & Mode, and By Supply & Demand) include a Legend panel on the left side of the page and a Filters panel on the right side:

- The Legend panel includes color and size legends. The By Commodity & Mode dashboard additionally presents symbology options.
- The Filters panel lets users select which elements—such as modes and commodities—to display on the dashboard.

Selected filters and toggles in these panels will apply to all maps, data tables, and graphs on a dashboard. In addition, some dashboards contain buttons and switches that let you update the data views for graphs:

- By Commodity & Mode includes buttons beneath the map that will update the graphs for different results breakdowns and measures.
- By Supply & Demand includes a switch beneath the map that toggles the graphs between facility utilization and demand/supply utilization.

On any dashboard, hover over an item on a map or chart (e.g., bar, icon, point, etc.) to display a tooltip which contains additional data.

**Resolving dashboard display issues**

Users may notice display issues in FTOT's Tableau outputs where dashboard text is too big or disappears altogether. Try the following steps to resolve display issues:

- Go to the folder that contains the tableau.exe file. This file is located in a folder like C:\Program Files\Tableau\Tableau 2020.3\bin.
- Right-click on tableau.exe, open “Properties”, and go to the “Compatibility” tab.
- Click the “Change high DPI settings” button
- Check the box to override high DPI scaling behavior. Set the “Scaling performed by” drop-down box to “System”.
- Restart the computer to ensure settings update.

### 6.2.2 FTOT Tableau Dashboard Panels

The first story point (Figure 11) is the supply chain summary which indicates the locations and relative size of the facilities in the supply chain. Demand centers are displayed with orange squares. The supply centers have green circles. The user can filter the facilities shown on the right-hand side under the Facility Type and Commodity filters. Hovering over an individual icon will provide a tooltip with a list of commodities and quantities for an individual facility, and the quantity of material available by facility type is shown in the table below the map.

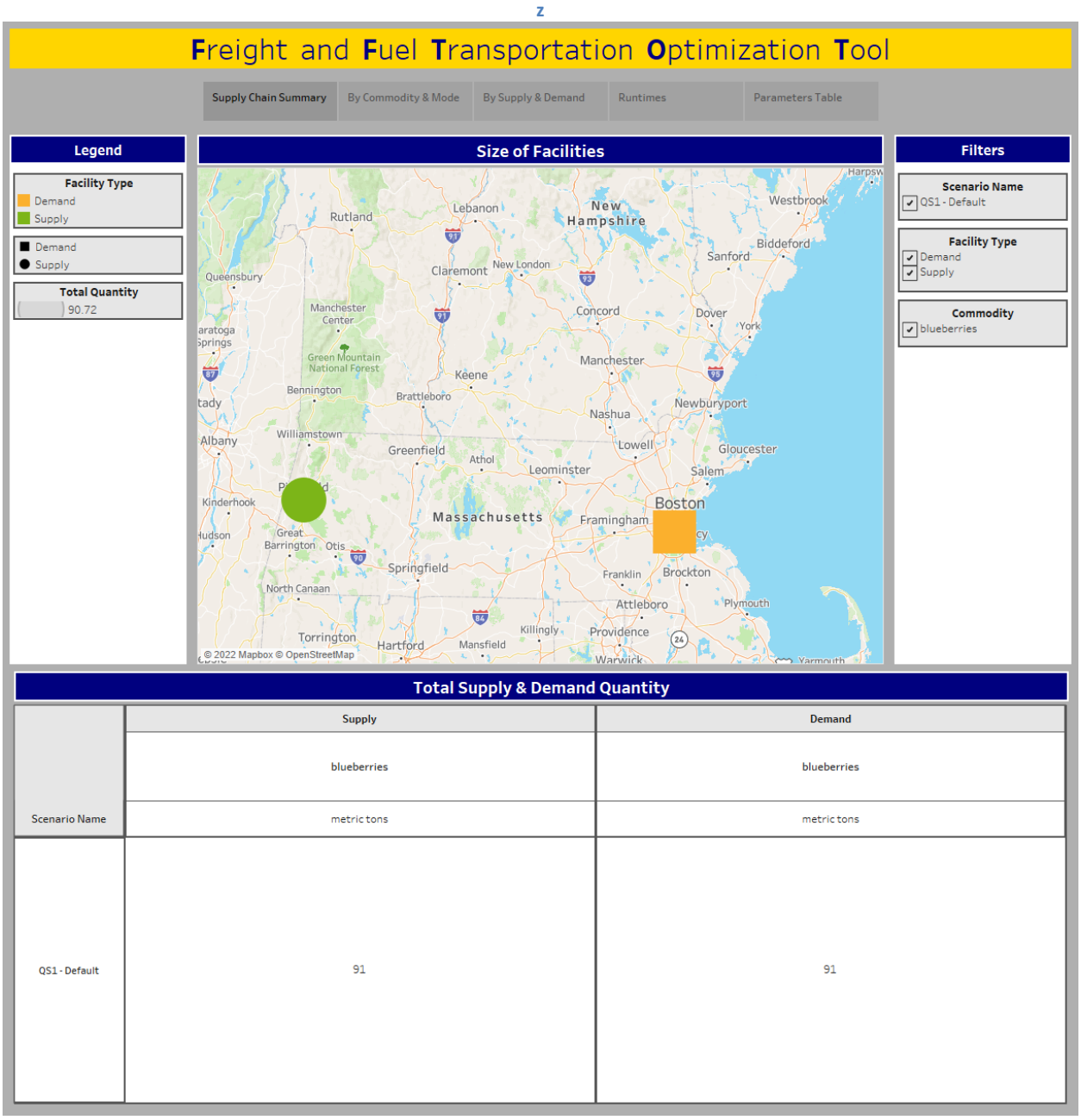



Figure 11: Tableau Story – Supply Chain Summary Dashboard

The By Commodity & Mode story point (Figure 12) shows the routing results for the optimal solution. Routes can be colored using the legend options on the left-hand side of the screen. Options include coloring by mode (as shown), commodity, and scenario name (this becomes more useful when comparing multiple scenarios). The filters on the right-hand side allow the user to turn various elements on or off, and it applies to both the map and the results summary chart at the bottom of the dashboard. Scenario filters include scenario name, mode, and commodity. Results are reported by FTOT include dollar cost, material moved, vehicle miles traveled (VMT), fuel burn, and carbon dioxide ($CO_2$) emissions. The results can be graphed and grouped by commodity or commodity and mode.

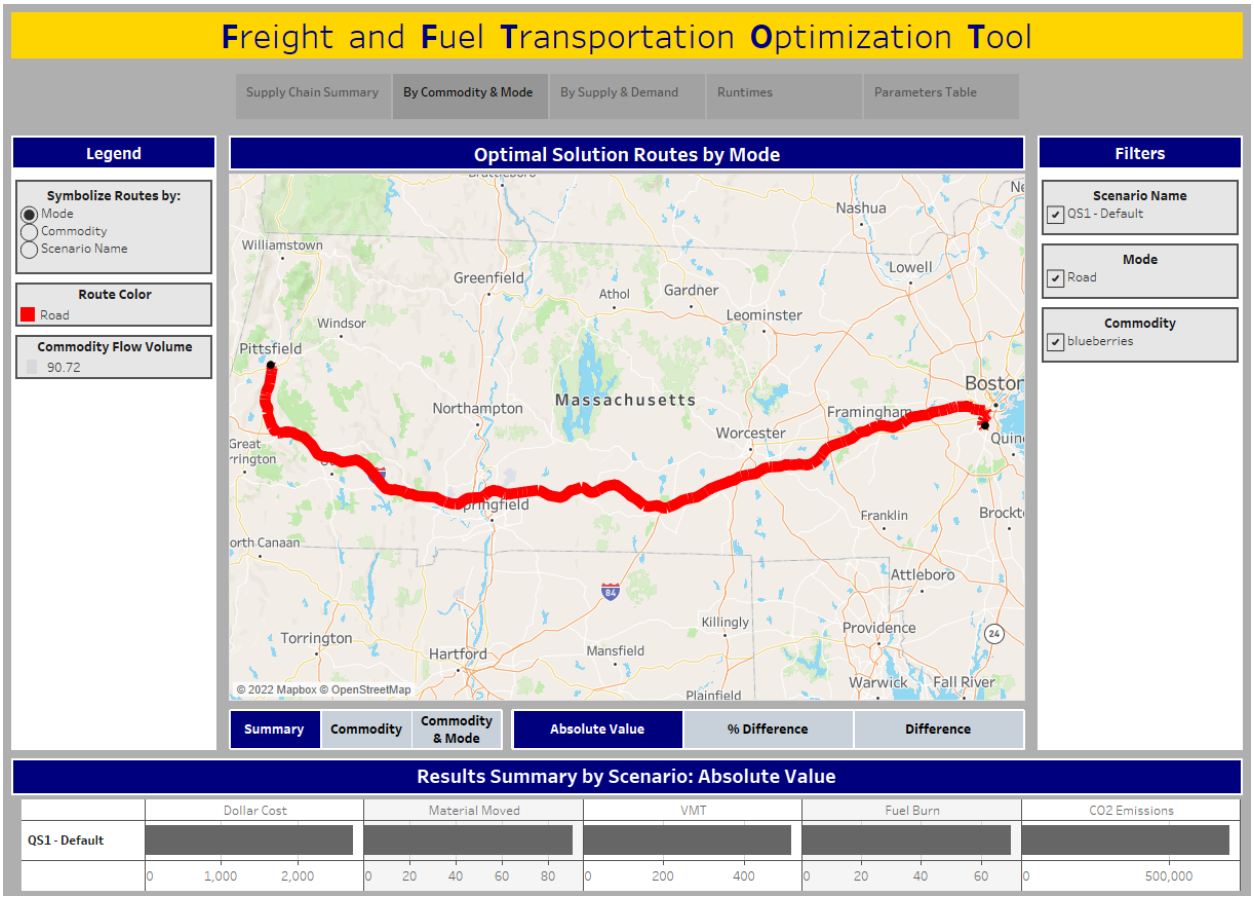



Figure 12: Tableau Story - Results by Commodity and Mode

The By Supply & Demand story point (Figure 13) summarize the optimal results by facility. The Size & Utilization of Facilities Map shows the relative size of supply and demand facilities, as well as the utilization of those facilities. The user may toggle between facility counts and total quantities using the slider under the map.

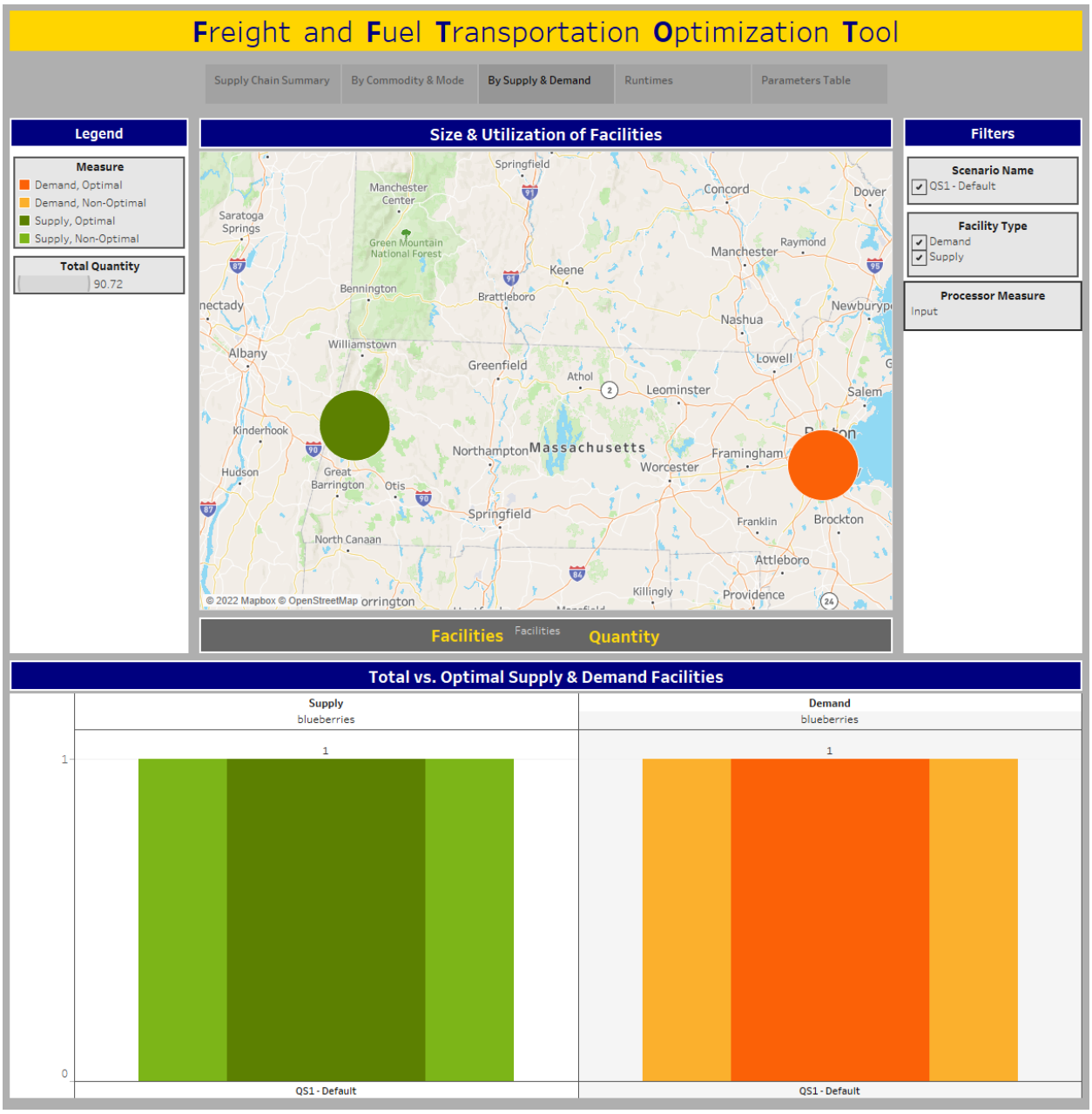



Figure 13: Tableau Story - Results by Supply and Demand

The Runtimes story point (Figure 14) summarizes the runtimes of each step in the run, as well as the cumulative total runtime. Hovering over an individual color will provide a tooltip with additional information.

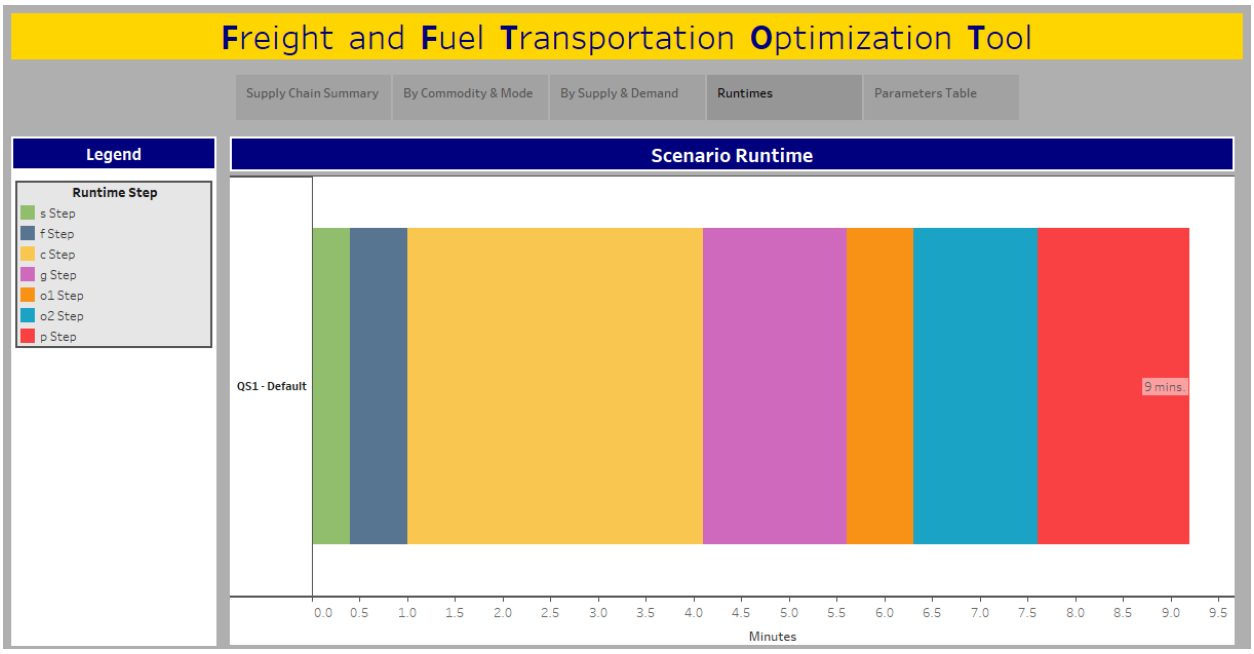
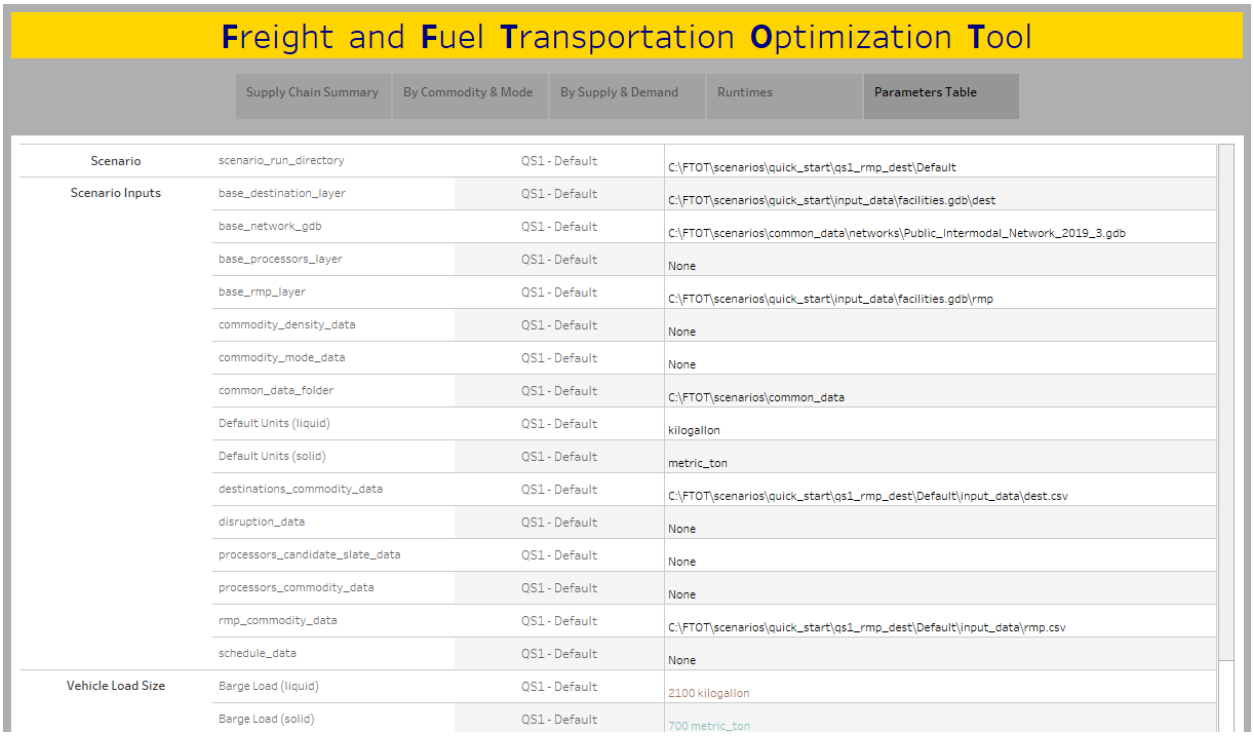



Figure 14: Tableau Story - Runtimes

The Parameters Table dashboard is the last story point (Figure 15). It shows the parameters used in the scenario. Parameters are grouped together by sections, such as cost per mode, emissions factors, and vehicle load sizes.




| | | | |
|---|---|---|---|
| Scenario | scenario_run_directory | QS1 - Default | C:\FTOT\scenarios\quick_start\qs1_rmp_dest\Default |
| Scenario Inputs | base_destination_layer | QS1 - Default | C:\FTOT\scenarios\quick_start\input_data\facilities.gdb\dest |
| | base_network_gdb | QS1 - Default | C:\FTOT\scenarios\common_data\networks\Public_Intermodal_Network_2019_3.gdb |
| | base_processors_layer | QS1 - Default | None |
| | base_rmp_layer | QS1 - Default | C:\FTOT\scenarios\quick_start\input_data\facilities.gdb\rmp |
| | commodity_density_data | QS1 - Default | None |
| | commodity_mode_data | QS1 - Default | None |
| | common_data_folder | QS1 - Default | C:\FTOT\scenarios\common_data |
| | Default Units (liquid) | QS1 - Default | kilogallon |
| | Default Units (solid) | QS1 - Default | metric_ton |
| | destinations_commodity_data | QS1 - Default | C:\FTOT\scenarios\quick_start\qs1_rmp_dest\Default\input_data\dest.csv |
| | disruption_data | QS1 - Default | None |
| | processors_candidate_slate_data | QS1 - Default | None |
| | processors_commodity_data | QS1 - Default | None |
| | rmp_commodity_data | QS1 - Default | C:\FTOT\scenarios\quick_start\qs1_rmp_dest\Default\input_data\rmp.csv |
| | schedule_data | QS1 - Default | None |
| Vehicle Load Size | Barge Load (liquid) | QS1 - Default | 2100 kilogallon |
| | Barge Load (solid) | QS1 - Default | 700 metric_ton |

Figure 15: Tableau Story - Parameters Table

## @@ 6.3 Maps

The FTOT map outputs are saved in the scenario's **.\Maps** directory and include the following:

- The multimodal network used in the optimization (01_S_Step)
- Raw Material Producers (02a_F_Step_RMP, 02a_F_Step_With_Labels)
- User Defined Processors (02b_F_Step_User_Defined_PROC, 02b_F_STEP_User_Defined_PROC_With_Labels)
- Ultimate Destinations (02c_F_Step_DEST, 02c_F_Step_DEST_With_Labels)
- All Facilities (02d_F_Step, 02d_F_Step_With_Labels)
- Processor Candidates (03a_F2_Step_Processor_Candidates, 03a_F2_Step_Processor_Candidates_With_Labels)
- All Processors (03b_F2_Step_Processors_All, 03b_F2_Step_Processors_All_With_Labels)
- Final Optimal Routes (04a_O_Step_Final_Optimal_Routes_with_Commodity_Flow, 04b_O_Step_Final_Optimal_Routes_with_Commodity_Flow_NO_LABELS. 04c_O_Step_Final_Optimal_Routes_with_Commodity_Flow_JUST_FLOW)
- Optimal and Non-Optimal Raw Material Producers (04d_O_Step_Optimal_and_Non_Optimal_RMP)
- Optimal and Non-Optimal Processors (04e_O_Step_Optimal_and_Non_Optimal_PROC)
- Optimal and Non-Optimal Ultimate Destinations (04f_O_Step_Optimal_and_Non_Optimal_DEST)

All map names are suffixed with the following text—"default_basemap, "gray_basemap", "topo_basemap", or "streets_basemap"—based on the version of the mapping that is specified in the run.bat file for the scenario.

Running the default "m" step produces maps utilizing the default FTOT basemap, replacing "m" with "mb" produces maps utilizing the Esri light gray basemap, replacing "m" with "mc" produces maps utilizing the Esri topographic basemap and replacing "m" with "md" produces maps utilizing the Esri streets basemap. In general, the default basemap is adequate for national and large regional scenarios, while the gray, topographic, and streets basemaps are more appropriate for smaller regional and local scenarios.

Note that many maps include variations that include/exclude labels. Since each scenario is different and all the maps are automated, some variations may work better than others depending on the scenario.

The user can manually develop their own maps within ArcGIS Pro leveraging the project file automatically generated in each scenario's output. To produce customized maps that are automatically output directly to the maps folder within an FTOT scenario, the user must edit the ftot_maps.aprx provided in the FTOT common_data folder and add user-specified and user-symbolized map data within the group layers located under the "CUSTOM_USER_CREATED_MAPS" section of the project file's Table of Contents. If these group layers are populated with actual data, FTOT will export these maps when the mapping step is run.

If the optional m2 Step of FTOT is run, additional time and commodity specific mapping is output into the scenario's Maps_Time_Commodity folder. These include:

- Maps showing location of flows for each commodity in the scenario
- Maps showing location of flows for each time step in the scenario
- Maps showing location of flows for each commodity/time step combination in the scenario
- An animation (.gif) representing flows for all time steps in the scenario

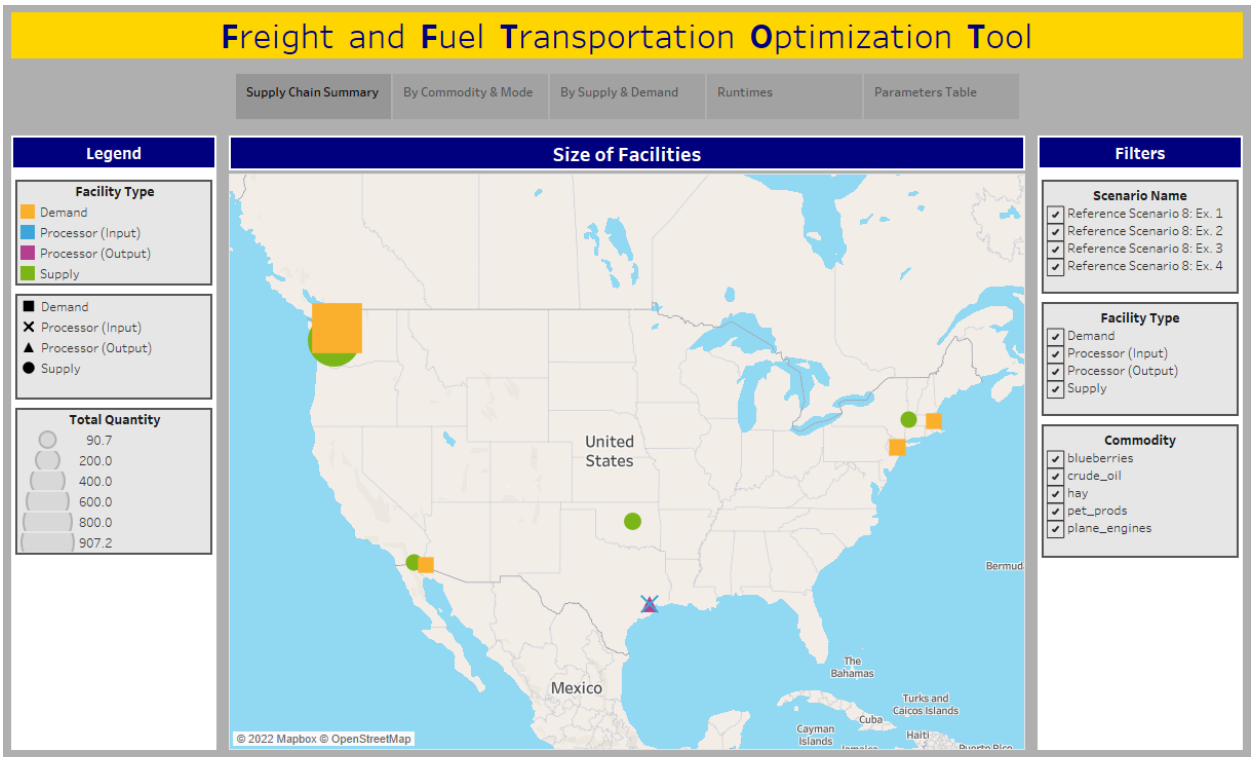
Like the m step, alternative basemaps can be run by replacing the m2 step in the bat file with m2b (gray basemap), m2c (topographic basemap), and m2d (streets basemap).

## 6.4 Tableau Scenario Comparison Dashboard

The scenario comparison dashboard provides the ability to compare multiple scenarios in the Tableau dashboard. Functionality includes options to change the color of mapping route results by mode, commodity, and scenario name, as well as a Tableau Story format that allows users to step through each of the following dashboards:

- Supply Chain Summary
- Route Results by Commodity and Mode
- Facility Results by Supply and Demand
- Run Times
- Parameters

The scenario comparison dashboard can be created using the Scenario Compare Tool detailed in Section 7.2. The Scenario Compare Dashboard resembles the individual scenario dashboard with a few notable differences detailed in the following subsections.



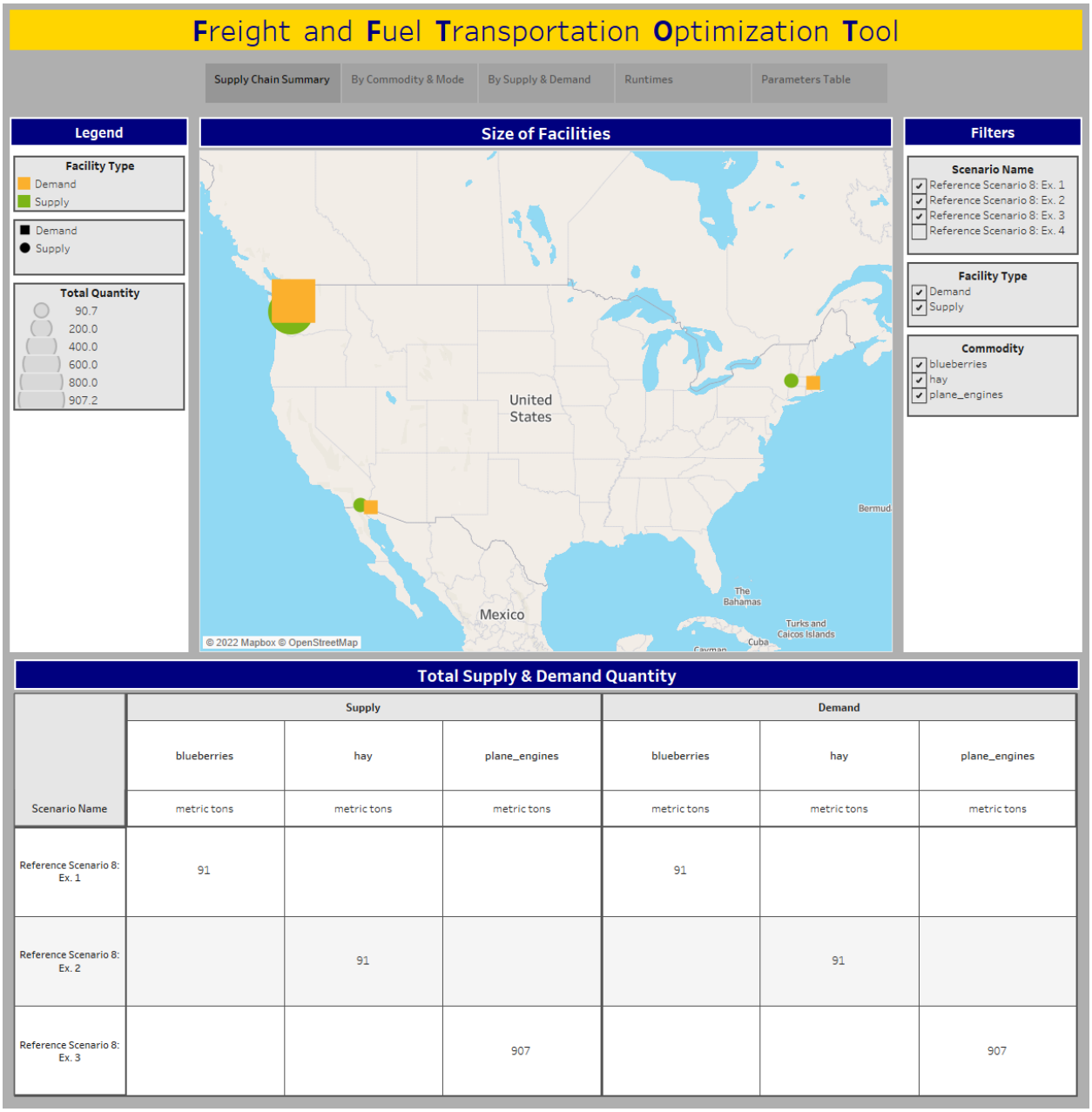

**Total Supply & Demand Quantity**

| | Supply | | | | Demand | | | |
|---|---|---|---|---|---|---|---|---|
| | blueberries | crude_oil | hay | plane_engines | blueberries | hay | pet_prods | plane_engines |
| Scenario Name | metric tons | kilogallon | metric tons | metric tons | metric tons | metric tons | kilogallon | metric tons |
| Reference Scenario 8: Ex. 1 | 91 | | | | 91 | | | |
| Reference Scenario 8: Ex. 2 | | | 91 | | | 91 | | |
| Reference Scenario 8: Ex. 3 | | | | 907 | | | | 907 |
| Reference Scenario 8: Ex. 4 | | 100 | | | | | 100 | |

Figure 16: Supply Chain Summary on a scenario comparison dashboard (Reference Scenario 8)

### 6.4.1 Filtering Results

The filters are located on the right-hand side of the dashboard. The filters turn off the scenario results from the graphs, maps, and charts throughout. When Reference Scenario 8: Ex. 4 is disabled in the filter, the map and supply chain table update automatically.




| Scenario Name | Supply | | | Demand | | |
|---|---|---|---|---|---|---|
| | blueberries | hay | plane_engines | blueberries | hay | plane_engines |
| | metric tons | metric tons | metric tons | metric tons | metric tons | metric tons |
| Reference Scenario 8: Ex. 1 | 91 | | | 91 | | |
| Reference Scenario 8: Ex. 2 | | 91 | | | 91 | |
| Reference Scenario 8: Ex. 3 | | | 907 | | | 907 |

Figure 17: Supply Chain Summary for subset Exercises 1, 2, and 3 (Reference Scenario 8).

### 6.4.2 Route Results

Returning to all four exercises again, the route results are displayed in the By Commodity & Mode dashboard. A high-level scenario summary indicating the percent difference of scenario cost, material moved, VMT, fuel burn, and $CO_2$ emissions are displayed relative to the first ("Baseline") scenario. The results can be investigated in more detail and visualized in a number of different ways. The left-hand side legend provides three options for the route colors including mode, commodity, and scenario name. Additional graphs of the data can be used by selecting the different buttons below the maps. There is the high-level summary by scenario, a commodity summary, and a commodity + mode summary. The

legend coloring options on the left-hand side, and the filters on the right-hand side also change the result tables below.

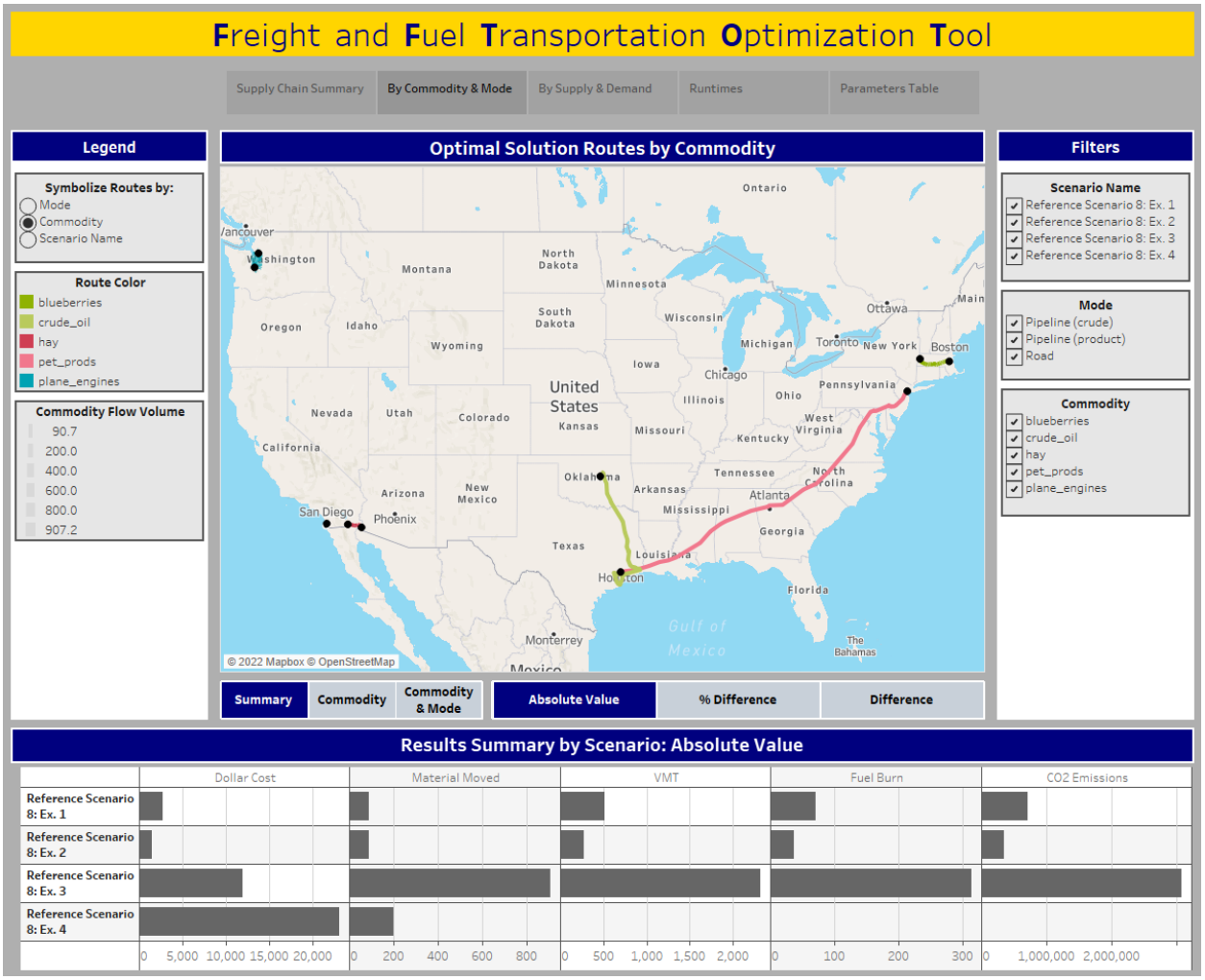



Figure 18: By Commodity & Mode results for Exercises 1, 2, 3, and 4 (Reference Scenario 8).

# @@ 7 FTOT SUPPLEMENTARY TOOLS

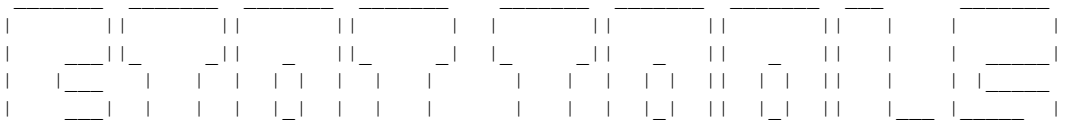
## 7.1 FTOT Tools

A set of supplementary FTOT tools is provided with the program through ftot_tools.py to assist the user with a variety of common tasks. These tools include the following:

- **xml_tool:** Generates an XML scenario file based on either a 1) FTOT template with defaults or 2) existing, older user-generated XML file. Note: Make sure to confirm the correct scenario values if updating an older XML file.
- **bat_tool:** Generates a bat file for running a new FTOT scenario based on user-provided inputs.
- **scenario_compare_tool:** Concatenates the results from one or more scenarios into a packaged Tableau workbook. The tool has two steps: (i) the user specifies an output directory where the concatenated results workbook will be stored, (ii) the user specifies the input directories which contain the results to be concatenated. This can be done recursively by supplying a top-level directory to automatically generate a list of sub-directories, or the user providing the scenario directories individually. See Section 6.4.
- **aggregate_raster_data**: Aggregates grid cell production data (e.g., USDA) by county.
- **generate_template_csv_files:** Generates the input data CSV files for RMPs, processors, and destinations. The template for RMP input does not include the optional max_transport_distance field, so the user should add this if necessary (notably when running candidate generation scenarios).
- **breakpoint:** Sets a python debugger breakpoint and enters a debugging REPL
- **replace_xml_text:** A tool to batch replace XML configuration elements recursively through a top-level directory. Useful for making changes to a number of scenario files, such as changing the base network geodatabase location.
- **network_disruption_tool:** Allows the user to automatically generate a network disruption CSV associated with a hazard scenario (e.g., NOAA sea level rise data, HAZUS data, etc.). In order to use this tool, you must have raster-based GIS data which identifies exposure levels due to some sort of hazard (e.g., flooding, earthquakes, etc.). Currently, this tool is only able to identify disruption of the road and rail portion of the default FTOT network. See Section 7.3.

The user is welcome to use any of the supplementary FTOT tools listed but testing and documentation is only provided for the scenario compare tool (Section 7.2) and the network disruption tool (Section 7.3). The remaining supplementary FTOT tools may require some Python development on the user's end. The FTOT tools interface can be accessed by running the following in a command-line window:

```
%python_path% c:\ftot\program\tools\ftot_tools.py
```



```
|   |      |   |  |       |  |   |      |   |  |       ||       ||       | _____| |
|___|      |___|  |_______|  |___|      |___|  |_______||_______||_______||_______|

version 0.1

select an option below to activate a tool
-----------------------------------------
[0] xml_tool
[1] bat_tool
[2] scenario_compare_tool
[3] aggregate_raster_data
[4] generate_template_csv_files
[5] replace_xml_text
[6] network_disruption_tool
[7] breakpoint
[8] exit
>>
```

Users who set up FTOT using the simple_setup.bat script can replace the %python_path% environment variable with their Python path: C:\FTOT\python3_env\python.exe.

The remainder of this section documents some of these tools in more detail, in addition to other adaptations of FTOT that have been developed over the years which help extend FTOT functionality.

## 7.2 Scenario Compare Tool

The Scenario Compare tool is a supplemental FTOT Tool used to concatenate the results from one or more scenarios in a list. The scenario compare tool automates the process of creating a Tableau Scenario Comparison Dashboard (see section 6.4 for more details). To run the tool, run ftot_tools.py and select Option 2 (scenario_compare_tool).

The tool has two modes to generate the list of scenarios to concatenate: an automatic recursive search, and a user-specified search. In the recursive mode, the user provides a high-level directory and FTOT returns all sub-directories within it. In the manual mode, the user specifies which scenario folders should be added to the list until specifying the “done” keyword.

After the list is established (either automatically with the recursive search, or manually) the tool will search for Tableau workbooks within the .\Reports subfolder, find the latest version, and concatenate the tableau_report.csv and tableau_output.gdb.zip records into the compare files. Any subfolders without a Reports folder are skipped.

Once the data is concatenated, the tool zips the workbook, CSV report, geodatabase, and supplement files into a packaged workbook file (.twbx). The user can open this packaged workbook using Tableau Reader, which is available as a free download. The comparison dashboard allows the user to select one or more scenarios to compare against.

For more specific steps:

- Select the `Scenario Compare Tool` from the ftot_tools.py menu and follow the prompts. First specify an output folder for the tool to put the concatenated results and packaged Tableau

workbook. If the folder does not exist, FTOT will create it, place temporary files, and open the window for you. For example, try:

```
c:\FTOT\scenarios\reference_scenarios\rs8_scenario_compare_dashboard\compare
```

```
You called compare_tool()

FTOT scenario comparison tool

------------------------------

scenario comparison tool | step 1/2:

------------------------------

scenario comparison output directory:

---------------------->
C:\FTOT\scenarios\reference_scenarios\rs8_scenario_compare_dashboard\compare
```

- Next, FTOT needs to generate a list of directories to search for the individual Tableau reports. The user can select two modes: (i) a recursive sub-folder search, or (ii) manually provide the paths to the scenarios. Select the recursive search (option 1) for this exercise, and then specify the RS8 directory (note: this is **not** the compare directory!)

```
C:\FTOT\scenarios\reference_scenarios\rs8_scenario_compare_dashboard
```

```
scenario comparison tool | step 2/2:

------------------------------

Option 1: recursive directory search

Option 2: user-specified directories

Enter 1 or 2 or quit: >> 1

enter top level directory

---------------------->
C:\FTOT\scenarios\reference_scenarios\rs8_scenario_compare_dashboard
```

- Once the list of scenarios is created, the tool will loop through each subdirectory under the RS8 suite, search for the .\Reports folder, and find the latest reports_YYYY_MM_DD_HH-MM-SS folder. If there are no .\Reports folders, then the tool skips that folder.

- The records in the tableau_report.csv and tableau_output.gdb files from the latest report are then concatenated into the comparison files stored in the output directory.

When all of the scenario directories have been searched, the concatenated results files are zipped up into a packaged workbook. Open the scenario compare dashboard by double clicking the `tableau_report.twbx` file.

**Input**

The required input for this tool is a set of at least two already run FTOT scenarios. The paths to each scenario must be defined manually or the parent path containing all scenarios to be compared must be defined (and the scenarios will be identified through a recursive search). The user must also define an output directory to store the scenario comparison dashboard.

**Output**

The output is a Tableau workbook providing tables and visualizations comparing each scenario. More information on interpreting the Scenario Comparison Dashboard is provided in Section 6.4.

## 7.3 Network Disruption Tool

The network disruption tool helps automate the process of creating a network disruption dataset for an FTOT scenario (see Section 4.1.2). To run the tool, run ftot_tools.py and select Option 6 (network_disruption_tool).

**Input**

The required input for this tool is a GIS-based raster dataset representing exposure data. The user also specifies the name of the dataset's attribute which specifies the exposure level, defines a search tolerance and the modes to which they want to apply disruption (currently limited to road and rail). The tool then automatically finds the maximum exposure level within the specified tolerance (distance) for each network segment.

**Output**

The output is a comma-delimited file (CSV) defining the unique segment IDs which are disrupted by the relevant exposure data, in the format FTOT can process. This disruption file can then be referenced in the relevant scenario's configuration XML.

## 7.4 Network Resiliency and Link Removal Tool

FTOT-Public-Link_Removal is a modification of the base FTOT program to assess the resilience of an FTOT optimal solution to disruption. The link removal resiliency testing process works as follows: (1) a baseline FTOT run is completed using a modified version of FTOT which retains additional network information, (2) network edges are ranked by importance (the default importance metric is

betweenness-centrality[22], but the user can also specify an importance metric), (3) disruptions are applied by removing edges from the optimal solution, (4) new optimal solutions are calculated for the disrupted network, (5) total scenario costs are calculated and compared. The importance calculations are for the road network only.

To install the FTOT-Public-Link_Removal code, follow the instructions available here on the GitHub repository for the modified FTOT code and the rank and removal code. The rank and removal code are run through a Jupyter notebook, and generate an interactive report of the resilience results. A presentation of the use of the tool is available, as is a video recording of a demonstration.

## 7.5 Supply Chain Resilience Tool

FTOT-SCR is a modification of the base FTOT program to support analysis of supply chain resilience. The supply chain resilience assessment includes two parts: integrated risk assessment to capture the combined effects of multiple risk factors on supply chain performance, and resilience assessment to calculate the long-term supply chain resilience in planning horizon. The supply chain methodology and modifications to the FTOT code were developed at Washington State University (WSU).

To install the FTOT-SCR code, follow the instructions available here on the GitHub repository for the modified tool. After installing, follow the instructions in the "Running the Scenario" section to run the two batch files to generate input data and analyze the resilience of the supply chain. The repository also contains two additional documents developed by the WSU team about the methodology used to create input data for the tool as well as the analysis performed in the tool.

[22] Freeman, Linton C. "A Set of Measures of Centrality Based on Betweenness." *Sociometry* 40, no. 1 (1977): 35–41. https://doi.org/10.2307/3033543.

# 8 TROUBLESHOOTING

| Issue | Action |
|---|---|
| When running FTOT in a command line window, the user immediately receives the following message: "The system cannot find the path specified". | Confirm that the paths defined in the scenario's batch file are appropriate. This issue is usually due to you having an FTOT Python environment stored in something other than the default location (C:\FTOT\python3_env\python.exe). If so, the Python environment variable needs to be adjusted slightly to reflect the path to your version of Python. The user can also confirm that your XMLSCENARIO and FTOT paths are set appropriately. |
| When running FTOT in a command line window, the user receives the following error towards the beginning of an FTOT run:<br><br>"You will need ArcGIS Pro 2.6 or later to run this script. Exiting." | Assuming the user does indeed have ArcGIS Pro 2.6 or higher installed, confirm that the license to use ArcGIS Pro is available (try opening up ArcGIS Pro in its own window). If not, you may need to connect to your work network or a VPN in order to access the license—contact your ArcGIS Pro license administrator for further details. |
| Import errors. Python is missing a required module. | See the installation guide in Section 2 and verify that the module is installed in the FTOT ArcGIS Pro Python environment. |
| Module version compatibility. | FTOT requires additional Python modules that are not part of the default ArcGIS Pro Python environment. These are automatically installed by the simple_setup.bat file, but only certain versions of each module have been tested by the FTOT team to be compatible. See Section 2 for this list. |
| Batch file (run.bat) does not run. | User may need to include 'python' on the lines specifying the process. For example, the user would insert a 'python' before the syntax that runs the process. In pseudocode:<br><br>python PythonScriptFilePath XMLfilePath ProcessYouWantToRun<br>USAGE EXAMPLE: python C:\FTOT\Program\python.py C:\FTOT\Scenarios\midwest1\scenario.xml |
| FTOT cannot find a GIS feature class or facility commodity CSV file and throws and exception error and exist program. | Ensure that the appropriate scenario assets exist, and the path is properly specified in the XML. |
| FTOT failes during the O2 step with an "IOError: [Errno 13] Permission denied". | This may be due to specific constraints within your work network or VPN. Try running FTOT on a different network and/or off the VPN to see if it resolves the issue. |
| FTOT scenario run results in a no-flow solution. | Potential causes:<br>• The unmet demand penalty is too low. Adjust the unmet demand penalty in the scenario configuration file. In general, it may be necessary to raise this penalty when any other cost (e.g., rail transport) is raised, or else the optimizer will conclude that it is more optimal to transport less material. As a general guide, the unmet demand penalty will likely work best if set to be 10-50 times the average actual transportation cost. It is advised to run |

| | |
|---|---|
| | scenarios with multiple unmet demand penalties to explore the sensitivity of a given analysis.<br>• The candidate processing facility capital cost is too high. Increase the unmet demand penalty in the scenario configuration file or decrease the capital cost in the processors candidate commodity CSV file.<br>• The processing facility lower bounds are too high. Adjust the minimum processor size in the facility commodity CSV file. In scenarios involving candidate generation, a no-flow solution will occur if a value for maximum transport distance is not specified in the raw material producer commodity CSV file. Ensure that a maximum transport distance (in miles) is specified.<br>• No-flow solutions are possible if facilities are not located close enough to segments in the FTOT transportation network. To address, raise the artificial link distances specified in the scenario's XML to ensure facilities connect to the network (for most modes, the default artificial link distance is 5 miles). Lack of connectivity is unlikely unless facilities are located far away from populated areas or are located outside of the continental United States, which is the current extent of the FTOT transportation network.<br>• For capacity-constrained scenarios where existing background flows are being considered, no-flow solutions are possible when facilities are not accessible due to capacity constraints. Turn off the capacity constraint or increase the minimum available capacity in the scenario XML to address this issue. |
| Tableau Display Issue: dashboard text is too big or disappears altogether. | • Go to the folder that contains the tableau.exe file. This file is located in a folder like C:\Program Files\Tableau\Tabelau 2020.3\bin.<br>• Right-click on tableau.exe, open "Properties", and go to the "Compatibility" tab.<br>• Click the "Change high DPI settings" button<br>• Check the box to override high DPI scaling behavior. Set the "Scaling performed by" drop-down box to "System".<br>• Restart the computer to ensure settings update. |

## 8.1 Known Bugs and Issues

- Errors with very large numbers:
    - If it seems like numbers are being capped or cut off in unexpected ways, the most likely cause is an improperly set constraint – double check the upper and lower bounds on processing facility flow, transportation and transloading costs, and demand vs production values. If none of those address the problem, it is possible that limitations of the programming language in handling very large numbers are having an impact. The

COINMP_DLL solver is written in C++, which limits values depending on the data type to ±2,147,483,647 (Integer), 38 places (Float), 308 places (Double).

# 9 ACKNOWLEDGEMENTS

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# Appendix A. Scenario XML Elements

The following is a description of each element and parameter in the scenario XML input file. Default values for several XML parameters and their sources can be found in Section 3.10 of the FTOT Technical Documentation.

1. <Scenario xmlns="Schema_v6.0.0"> - the namespace used by the XML schema. This should not be modified by the user. The latest version of the XML schema is not compatible with FTOT 2021.2 or earlier versions.
2. <Scenario_Schema_Version> - the version of the schema. Used to verify against changes to the XML schema, and code changes. The convention is: version X.Y.Z, where X = major version of FTOT, Y = breaking change to XML/Schema/Code, Z = non-breaking change to XML/Schema/Code. If a breaking change is made to the schema or code, the user must upgrade their XML file to meet the new schema standard. Users can use FTOT's scenario update tool to generate the latest version of the default XML file or use one of the latest Quick Start scenario files as a template.
3. <Scenario_Name> - a short string used to identify the scenario in the reports and logs. Scenario Names should be descriptive but no more than about ten characters long. Note: scenarios names should be differentiated for purposes of analyzing results with the Tableau workbooks.
4. <Scenario_Description> - a string used to describe the scenario. This is printed out in the reports and useful to quickly determine what is different between otherwise similar scenarios. For example, if the unmet demand penalty is increased in a sensitivity analysis, or if the road network is shut off in the permitted mode list, the description is a great place to note this. Keep descriptions under 500 characters.
5. <Scenario_Inputs> - contains the following elements:
    a. <Common_Data_Folder> - contains several files that are required by FTOT to run. For example, the default national multimodal network. The ftot_maps.aprx, and tableau_dashboard.twb are used for generating maps and Tableau dashboards, respectively. The files listed in the common data folder are not modified by FTOT. Instead, FTOT copies a local copy to the scenario folder and modifies that version.
    b. <Base_Network_Gdb> - a string specifying the full path to the network geodatabase FTOT will setup and use for the scenario. FTOT will copy the base version to the local scenario. Therefore, a single base network can be used across multiple scenarios without impacting the base version.
    c. <Disruption_Data> - an optional string specifying the full path to the network disruption CSV that the scenario will leverage. If a disruption CSV exists, then the scenario will read it and remove any segments from the network identified in the table with a link availability of 0.
    d. < Base_RMP_Layer>, <Base_Destination_Layer>, <Base_Processors_Layer> - are defined by a string specifying the full path to the FC containing the respectively facilities that FTOT will use for routing. Again, FTOT will create a copy of the base FC to the local scenario geodatabase and leave the base version untouched. In the case of the

<Base_Processors_Layer>, it should be noted that these are user specified processor locations, and not candidates generated by the tool.

e. <RMP_Commodity_Data>, <Destinations_Commodity_Data>, <Processors_Commodity_Data>, <Processors_Candidate_Commodity_Data> - are full paths to the CSV files that are used to define the commodity-facility relationships. The RMPs by definition only have "output" commodities that define the available supply from the facility. Destinations only have "input" commodities that define the total demand of a commodity at the destination. Processors have both "input" and "output" commodities that define the facility size and product-slate/processing ratio. The Processor Candidates commodity data file defines the maximum and minimum facility size, processing size, and cost formula for the amortized capital cost of the facility.
f. <Schedule_Data> - an optional string specifying the full path to the schedules CSV file.
g. <Commodity_Mode_Data> - an optional string specifying the full path to the commodity mode CSV which allows the user to specify which commodities can travel on each mode, and by which vehicle type. This file is necessary to permit movement by pipeline.
h. <Commodity_Density_Data> - an optional string specifying the full path to the commodity density CSV which allows the user to specify commodity-specific density values to be used in calculating emissions for liquid commodities traveling by rail, water, or pipeline. If this parameter is omitted from the XML, the Density_Conversion_Factor parameter value (see below) will be applied to all liquid commodities.
i. <Default_Units_Solid_Phase> and <Default_Units_Liquid_Phase> - are used to specify the units in which FTOT will report the results. The Pint python module is used to convert the quantities and units specified in the commodity input CSV files into the default units specified in these tags. Pint is able to handle a wide range of units, prefixes, and abbreviations. At run time, FTOT will process the default units with a simple conversion test and raise an error if it cannot use the user specified values because of a typo.

6. <Assumptions> - contains the vehicle load, fuel efficiency, and $CO_2$ emission factors for each mode and phase of matter.
   a. Vehicle loads - quantities with units for the maximum load as defined for each mode and phase of matter (Truck_Load_Solid, Railcar_Load_Solid, Barge_Load_Solid, Truck_Load_Liquid, Railcar_Load_Liquid, Barge_Load_Liquid, Pipeline_Crude_Load_Liquid, Pipeline_Prod_Load_Liquid).
   b. Fuel efficiencies - rates with units of distance per volume as defined for each mode (Truck_Fuel_Efficiency, Rail_Fuel_Efficiency, Barge_Fuel_Efficiency).
   c. CO2 emission factors - rates with units of mass per distance (for road) or units of mass per weight per distance (for non-road) as defined for each mode (Railroad_CO2_Emissions, Barge_CO2_Emissions, Pipeline_CO2_Emissions). For road, emission factors are further broken down by category (Atmos_CO2_Urban_Unrestricted, Atmos_CO2_Urban_Restricted, Atmos_CO2_Rural_Unrestricted, Atmos_CO2_Rural_Restricted).
   d. <Detailed_Emissions_Reporting> - an optional True/False flag determines whether a separate report of non-$CO_2$ emissions is output by FTOT. The default value is False.

e. <Density_Conversion_Factor> - an optional number with units specifying the default density value used to calculate emissions for liquid commodities on the rail, water, and pipeline modes. The default density will be used for any liquid commodity not specified in the commodity density CSV input file. If this parameter is omitted from the XML, a default density value of 3.33 ton/kgal is used, as it is the density of kerosene, a proxy for sustainable aviation fuel.

7. <Create_Network_Layer_Script> - Updates each network link with the cost functions defined for each mode and link type by the user.
   a. <Network_Costs> - The GIS module assigns costs to each link in the multimodal network based on the transport costs specified in the XML Scenario file. The dollar costs on the GIS network are the dollar amounts required to transport material over each particular link. The default costs are defined in USD/kilogallon-mile for liquids, and USD/metric ton-mile for solid materials. The default cost values come from the US BTS average freight revenue per Ton-Mile. The 2018 data was used because it is the latest complete year reported in the table. The liquid costs were estimated by multiplying the solid values by 3.02 to convert between thousand gallons and metric tons, based on the FTOT default density value of 3.33 ton/kgal (the density of kerosene, used as a proxy for sustainable aviation fuel). The impedances apply a scaling factor to the base dollar cost. For example, FTOT is designed to prefer faster/larger links on the road network. Therefore, a multiplier of 1 is used for interstate highways, versus a multiplier of 1.3 for local roadways, resulting in a price of $0.00066/gallon·mile for interstate highways and $0.000858/gallon·mile for local roadways.[23] Each mode is defined in the <Modal_Costs> section.
      i. <Railroad> - In Volpe's internal FTOT network, rail impedance categories are based on FRA Rail Density Codes, which are sensitive, non-public data. In the public FTOT network, rail impedance categories are based on publicly available rail ownership data and whether or not the rail segment is part of STRACNET. In the public FTOT network, the final three impedance categories (Rail_Density_Code_2_Weight, Rail_Density_Code_1_Weight and Rail_Density_Code_0_Weight) are NOT utilized. These weights are used to encourage flows on portions of the rail network that see higher freight use (internal network) or part of STRACNET and associated with a Class 1 railroad (public network).
      ii. <Truck> - Weights are used to encourage flows on lower functional class roadways (e.g., interstates and highways). Truck_Interstate includes FAF Function Class 1. Truck_Principal_Arterial includes FAF Function Classes 2 and 3. Truck_Minor_Arterial includes FAF Function Class 4. Truck_Local includes all other FAF Functions Classes (excluding those above). More information on functional classes and the FAF road network is available at the following URL: https://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf4/netwkdbflow/index.htm

[23] Assuming that a large tanker truck holds 8000 gallons, this corresponds to a cost of $5.28 to $6.86 per truck-mile, depending on functional class. Truck travel speed was calculated based on the 2007 estimated peak period speed estimated in the FAF for each link, assuming a minimum floor of 15 mph.

iii. <Barge> - Water impedances are based on categorizing publicly available USACE freight volumes over the national waterway network. These weights are used to encourage flows on portions of the waterway network that see higher freight use. The default value of 10.0 for waterways with no volume is meant to discourage flows on portions of the waterway network with little to no documented freight use. Water_High_Volume includes waterways with volumes >= 10,000,000 tons. Water_Medium_Volume includes waterways with tonnage volumes < 10,000,000 and >= 1,000,000 tons. Water_Low_Volume includes waterways with tonnage volumes < 1,000,000 tons. Water_No_Volume includes waterways with no tonnage volumes documented. The source for the National Waterway Network and waterway network freight volume data is here: https://usace.contentdm.oclc.org/digital/collection/p16021coll2/id/1450

iv. <Intermodal_Transloading_Costs> - Intermodal costs specify the cost of switching from one mode on the network to another (e.g., rail -> road). Intermodal transfers can only take place as specified intermodal facilities on the network. A cost for solid material and a cost for liquid material transloading is specified by the user.

b. <Artificial_Links> - Since facilities are not always located directly on the multimodal network, artificial links must be used to connect facilities to the network. A reasonable default is 5 miles, though longer artificial link distances can be conceivably used, particularly for the pipeline network where there is the least amount of detail. Shorter artificial link distances can be used when the facilities are known to be located directly on or adjacent to the relevant network modes. Artificial links are only created for the permitted modes defined in the XML scenario file. Reporting on the artificial links created in a scenario is detailed in the section on FTOT outputs.

c. <Short_Haul_Penalties> - FTOT applies a penalty to rail and water artificial links to discourage short movements on those networks. Penalties are specific to the mode and phase of matter. Inputting a higher penalty value will further encourage transport by road.

8. <Route_Optimization_Script>

a. <NDR_On> - The True/False flag determines whether the network presolve step using the NetworkX shortest path algorithm is enabled. The default is for the presolve step to be disabled.

b. <Permitted_Modes> - The following True/False flags determine whether or not a particular mode should be allowed for routing any flows in the scenario. The default is for all modes to be on.

c. <Capacity_Options> - contains the following elements:

i. <Capacity_On> - The True/False flag determines whether network capacity should be considered as a constraint for flowing in the scenario. The default is for capacity to be off.

ii. <Background_Flows> - The following True/False flags determine whether or not a particular mode should have its existing (background) flows considered. If True, then background flows (e.g., existing movements of freight on the network) will be considered. The default is for all modes to NOT have their background flows considered.

iii. <Minimum_Capacity_Level> - The following setting (0-1) determines the minimum fraction of daily capacity that must be available for each network segment in the scenario. Setting a value above 0 allows network segments that are already at capacity due to existing flows, to be traversable in this scenario up to the minimum capacity level.

d. <Unmet_Demand_Penalty> - This parameter applies a cost to each unit of demand at a destination that is not fulfilled. It is used to drive flow in the scenario.