# Freight and Fuel Transportation Optimization Tool Reference Scenarios Documentation

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Volpe

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13. ABSTRACT (Maximum 200 words)

Volpe created the Freight and Fuel Transportation Optimization Tool (FTOT) to support the FAA, DOE, and the U.S. Navy's Office of Naval Research to assess optimal transport options for freight and fuel supply chains. 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/diesel) and fulfillment of downstream demand. This report documents a set of reference scenarios developed to help the user explore more advanced functionality of the FTOT public release 2022.2. This documentation is updated quarterly and available on the Public FTOT GitHub repository: https://github.com/VolpeUSDOT/FTOT-public

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# Reference Scenarios

## Overview

Assuming you have installed FTOT (instructions can be found in Section 2 of the FTOT User Guide) and run the initial Quick Start scenarios, this is the place to learn how to configure FTOT to run scenarios with more advanced functionalities and view the results. After downloading the reference scenarios, the directory and file path should look like this:

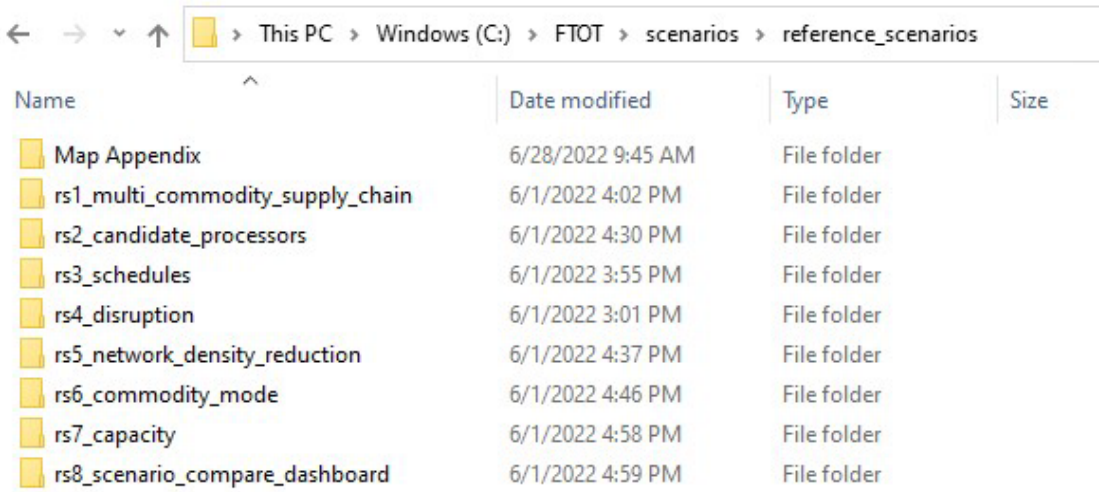


*Figure 1: FTOT reference scenarios folder structure.*

The Reference Scenarios series is a set of FTOT scenarios each designed to demonstrate how to configure a different aspect of FTOT functionality. In addition to demonstrating different FTOT functionalities, the reference scenarios can also serve as templates for creating user-specified scenarios. Depending on the type of supply chain scenario the user wants to model, they can use the corresponding reference scenario as a starting point. If developing custom scenarios from these templates, refer to the User Guide for more guidance. The eight reference scenarios are summarized in the table below.

| # | Summary | Functionality |
|---|---|---|
| 1 | *Multicommodity supply chain with intermediate processing steps* | Multiple processing steps; multi-input processors; multi-output processors; maximum processor capacity |
| 2 | *Candidate processing facilities* | FTOT-generated candidate processors; pre-determined candidate processors |
| 3 | *Facility schedules* | Schedules; maps by commodity and time |
| 4 | *Network disruption* | Disruption on network links; network disruption tool |
| 5 | *Network density reduction (NDR)* | NDR pre-solve method |
| 6 | *Commodity mode and vehicle types* | Commodity-mode restrictions; crude and product pipeline flows; custom vehicle types; detailed emissions reporting |
| 7 | *Capacity and background flows* | Enabling capacity by mode; background flows |

| # | Summary | Functionality |
|---|---|---|
| 8 | *Scenario comparisons* | Generating scenario comparison dashboard |

*Table 1: Reference scenarios summaries and demonstrated FTOT functionalities.*

**Getting Started**

- The user should refer to specific Reference Scenario sections in this document as best match their desired supply chain structure and functionalities. Each section details what changes need to be made to FTOT input files in order to turn on the feature within FTOT. The user is encouraged to run the Reference Scenario to see examples of the scenario run and outputs, and they can use the Reference Scenario folder and included input files as a template for creating their own scenario of that type.
- FTOT scenarios are stored in the C:\FTOT\scenarios\reference_scenarios folder. Within this directory, each scenario includes its own dedicated subfolder for storing the scenario configuration and outputs.
- Each scenario (e.g., rs1_multi_commodity_supply_chain) contains a batch script file called **run_vX_X.bat**, where the Xs denotes the version number of the batch file.
- You can run the batch script by double clicking it or manually executing it in the Command Prompt. 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 need to modify these paths for each batch script that you run to appropriately reflect the actual paths on your machine.

**Results**

- Informational logging is available in the command shell during the run. Detailed logging is available in the **.\logs** folder.
- The user is encouraged to read the logs to familiarize themselves with the FTOT operations occurring during each step.
- FTOT generates results in the **.\Reports** and **.\Maps** folders of the scenario. The reports and maps are timestamped.
- The report is found in a timestamped **reports** folder within the **.\Reports** directory of the scenario. The FTOT report 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.
- A Tableau Dashboard (**tableau_dashboard.twbx**) can also be found in the timestamped **reports** folder within the **.\Reports** directory of the scenario. This can be opened in Tableau Reader.
- The map files can be found 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.
- Maps generated by the Reference Scenarios can be found in the C:\FTOT\scenarios\reference_scenarios\Map Appendix folder. The user can compare the map files generated from their own scenario run against these to confirm the scenarios ran correctly.

For more information on interpreting results, see the complete FTOT Documentation, specifically the User Guide.

**More Information**

The Reference Scenarios documentation details the nuances of each run and provides brief overviews of the main results. The user is encouraged to run through these scenarios as fit their use case to become familiar with the specific input files and parameters associated with that type of scenario before creating their own**. It is highly recommended that the user read through the documentation for the Quick Starts first, as that contains the most detail.** This documentation for reference scenarios is more focused on highlighting the differences among scenarios and demonstrating various FTOT features.

**Troubleshooting**

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

# Contents

**Table of Figures and Tables**

# Reference Scenario 1 – Multi-Commodity Supply Chain

**Instructions: to run the Multi-Commodity Supply Chain Scenario, execute run_v6_1.bat in reference_scenarios\rs1_multi_commodity_supply_chain. The run should take between 30-40 minutes. A full description of this scenario is below, including the expected results.**

## Purpose

The purpose of the Multi-Commodity Supply Chain Scenario is to demonstrate how to model a more complex supply chain structure in FTOT. Concepts being modeled include processor facilities that can co-process two distinct input commodities, processor facilities that produce multiple output commodities, and a commodity that goes through two processing steps before reaching its ultimate destination. This FTOT scenario also demonstrates maximum input capacity for processing facilities.

## Input Data

The facility-commodity data files include additional RMP facilities to supply sugar and apples, and the processor facility commodity data file includes three types of processing facilities: (1) a facility that takes blueberries and sugar to make blueberry jam, (2) a facility that takes apples and sugar to make apple juice and apple butter, (3) a canning facility that converts apple butter to canned apple butter. The feature classes in the counties.gdb located in the **scenarios\common_data\facilities** folder are specified. The geospatial data feature classes in counties.gdb, with the corresponding facility names, can be opened in ArcGIS Pro; for the user's convenience, a PDF of some of these data can be found in the **scenarios\common_data\facilities** folder.

In this scenario, 100 tons of blueberries from rmp_25003, 100 tons of apples from rmp_33013, and 200 tons of sugar from rmp_25011 are supplied and sent to different processor facilities. At proc_25015, blueberries and sugar are specified as inputs and blueberry_jam is specified as the only output, and it is created at a ratio of 100 tons output per 100 tons of sugar + 100 tons of blueberries. The maximum processor input is set to 150 tons, which defaults the minimum processor input to one-half of the maximum input, or 75 tons. In general, the minimum input is adjustable by the user as well by including a new min_processor_input column in the proc.csv input file (see Section 3.3 of the FTOT User Guide for more information). This applies to the total input, which in this case means a minimum of 37.5 tons and a maximum of 75 tons for each of blueberries and sugar. For multi-input processors, all input commodities need to be provided in the same units. Note that the maximum input capacity values entered by the user in the facility-commodity data should be consistent across commodities for each facility. Also note that FTOT requires both commodities to be available in order to generate the output. If one of the input commodities is limited, then FTOT will generate up to the limiting amount of input material.

Similarly, proc_33011 converts 100 tons of apples and 100 tons of sugar into 75 tons of apple_juice and 75 tons of apple_butter, with a total maximum processor input of 200 tons. Finally, proc_25009 converts 100 tons of apple_butter to 100 tons of canned_apple_butter, modeling a canning facility with a total maximum processor input of 150 tons. Note how FTOT treats the commodities with distinct names to force the flow through the supply chain in the proper sequence.

## Running a Scenario

The scenario XML file includes facility-commodity CSV files for the RMP_Commodity_Data, Destinations_Commodity_Data, and Processors_Commodity_Data fields.

Execute the run.bat file in the RS1 scenario directory. The run.bat file specifies the same sequence of events as the Quick Start scenarios, since candidate generation for processors is not used.

## Viewing Results

Once the scenario is run, the user can compare their output maps to those in the Map Appendix folder within the reference_scenarios directory. The FTOT-generated map called 04a_O_Step_Final_Optimal_Routes_With_Commodity_Flow_default_basemap.png (Figure 2) shows the optimal supply chain routing.

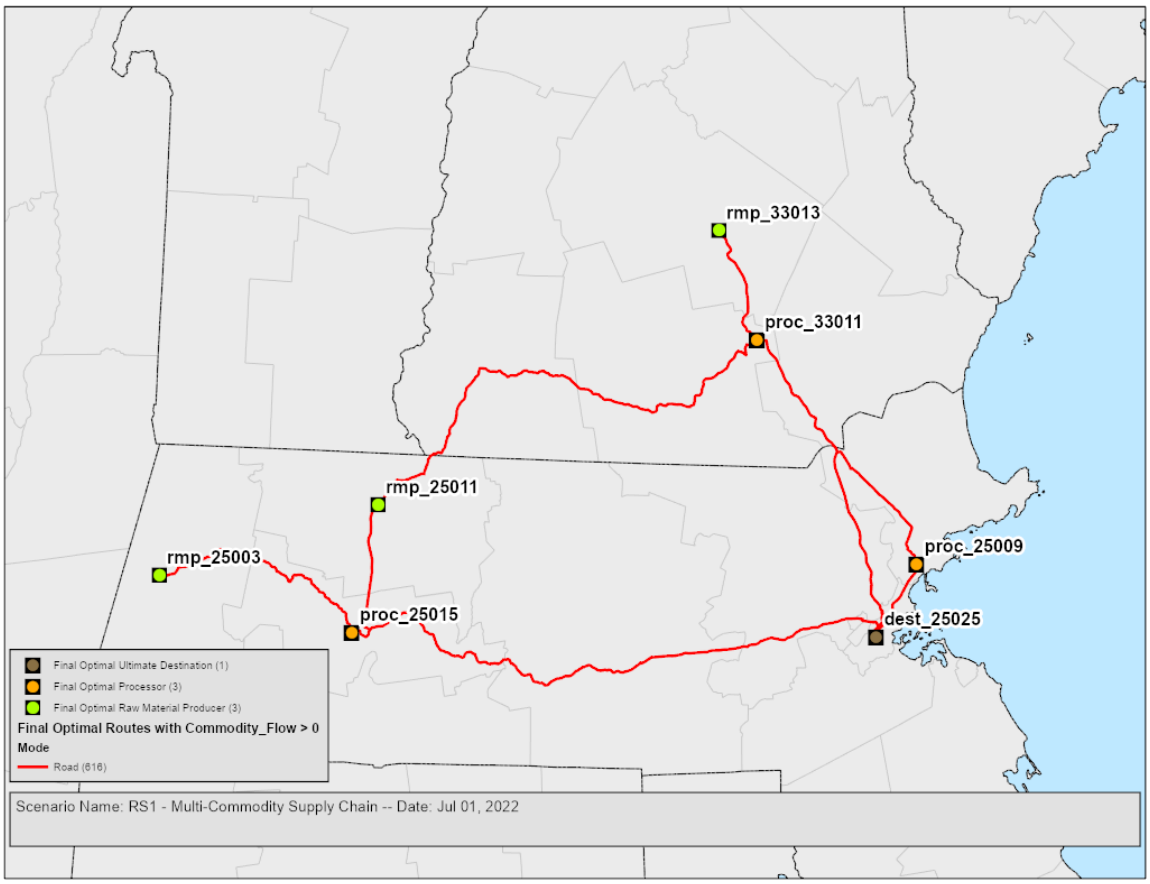


*Figure 2: Scenario 1 multi-commodity supply chain optimal solution map.*

The optimal solution shows that the material travels exclusively over the road network. All facilities (RMPs, processors, destination) are connected, with commodity flows passing through every facility.

More details on the optimal flow can be found in the text report in the timestamped reports folder in the .\Reports directory of the RS1 scenario. The “Scenario Total Flow of Supply and Demand” and the “Scenario Total Utilization of Supply and Demand” tables summarize the commodity flows in and out of facilities in the optimal solution. Note that while 100% of apple juice and canned apple butter demand are satisfied, only 75% of blueberry jam demanded is satisfied. This is due to the maximum input capacity constraint of the processor converting blueberries to blueberry jam. 25% of available blueberry supply and 12.5% of available sugar supply never leave the raw material producer facilities, as they cannot be utilized at the processor facility.

# Reference Scenario 2 - Candidate Processor Generation

**Instructions: to run the Candidate Processor Generation Scenario, execute run_v6_1.bat in reference_scenarios\rs2_candidate_processors. The run should take about 3-4 hours. A full description of this scenario is below, including the expected results.**

## Purpose

Scenario 2 increases the complexity of the supply chain by considering candidate processor facilities, including one defined by the user and several at locations FTOT generates between the two RMPs and the ultimate destination. In this scenario, FTOT does a pre-optimization step building out paths between the RMPs and destination to find where along the network sufficient material would flow to satisfy the requirements for building a candidate processor. FTOT then selects possible candidate locations and does a second optimization to compute the optimal flow, including costs from building the utilized FTOT-generated and user-defined candidate processors and flowing the commodity through a candidate processor where it is converted to a new material.

## Input Data

Several modifications to the input files are required to run a candidate processor generation scenario.

Two RMPs are specified in the rmp.csv file (shown below in Figure 3). The max_transport_distance field is included for both RMPs because the field is required to generate candidate processors. In this case, FTOT will not allow movements greater than 120 miles on the network for blueberries originating from either facility.

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | facility_name | facility_type | commodity | value | units | phase_of_matter | io | max_transport_distance |
| 2 | rmp_25003 | raw_material_producer | blueberries | 90 | tons | solid | o | 120 |
| 3 | rmp_25013 | raw_material_producer | blueberries | 70 | tons | solid | o | 120 |

*Figure 3: Scenario 2 raw material producer file (rmp.csv).*

A new facility-commodity CSV file is introduced in this scenario: proc_cand.csv. It contains six records for each type of processor facility: 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 required to place a candidate facility (min_aggregation), and cost_formula. In this case, candidate jammery processors convert 100 tons of blueberries to 100 tons of jam, with a minimum processor size of 50 and maximum size of 100. Additionally, since the minimum aggregation size is set to 10 tons, FTOT will generate a candidate where flows of blueberries aggregate with at least 10 tons. Finally, the amortized capital cost of the candidates is specified as a formula. In this case, 2 USD/ton of input material is specified. The amortized capital cost of the facility is added to the optimization problem and included in the total scenario cost.

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | facility_name | facility_type | commodity | value | units | phase_of_matter | io |
| 2 | candidate_jammery | processor | blueberries | 100 | ton | solid | i |
| 3 | candidate_jammery | processor | jam | 100 | ton | solid | o |
| 4 | candidate_jammery | processor | minsize | 50 | ton | solid | |
| 5 | candidate_jammery | processor | maxsize | 100 | ton | solid | |
| 6 | candidate_jammery | processor | cost_formula | 2 | USD/ton | | |
| 7 | candidate_jammery | processor | min_aggregation | 10 | ton | solid | |

*Figure 4: Scenario 2 candidate processor commodity file (cand_proc.csv).*

In the second round of optimization (the O1/O2 steps), FTOT considers both FTOT-generated processors and the user-defined candidate processor, which is provided in the proc.csv input file and contains a new column "build_cost" in its definition. The nonzero amortized build cost indicates that while facility location has been predetermined by the user, it is a candidate processor to be built. This facility would be located at the "proc_25015" county point feature if selected. The amortized cost to utilize this processor is 40 USD, making it less expensive per ton than the FTOT-generated candidate processors.

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | facility_name | facility_type | commodity | value | units | phase_of_matter | io | max_processor_input | build_cost |
| 2 | proc_25015 | processor | blueberries | 100 | tons | solid | i | 80 | 40 |
| 3 | proc_25015 | processor | jam | 100 | tons | solid | o | 80 | 40 |

*Figure 5: Scenario 2 processor commodity file containing user-defined candidate processor (proc.csv).*

## Running a Scenario

The scenario XML file includes facility-commodity CSV files for both the Processors_Commodity_Data and Processors_Candidate_Commodity_Data fields, the former containing information about the user-defined candidate and the latter containing parameters for FTOT-generated processors.

Execute the run.bat file in the Reference Scenario 2 directory. The run.bat file specifies a different sequence of steps than most FTOT runs. Refer to Section 5.1 of the User Guide for details on the FTOT scenario sequence for the candidate generation and selection process.

## Viewing Results

The report is found in a timestamped reports folder in the .\Reports directory. **To quickly check your results, look for the following lines in the generated report and compare your values to those below.**

```
RESULTS
------------------------------------------------------------------
...
OC :  Optimal Objective Value:   3,795
...
O2 :  Optimal Objective Value:   4,228
...
P_ :  BLUEBERRIES_DOLLAR_COST_ALLMODES:     879.62 :   USD
...
P_ :  CANDIDATE_JAMMERY_42828_PROCESSOR_INPUT_OPTIMAL_BLUEBERRIES_ALLMODES:          90.72 :     metric_ton
P_ :  PROC_25015_PROCESSOR_INPUT_OPTIMAL_BLUEBERRIES_ALLMODES:    54.43 :    metric_ton
```

## A note about Scenario 2 results

Due to the heuristic nature of the candidate generation algorithm that FTOT uses, there may be slight variations in the results you see across runs of this scenario. That is to be expected, and it does not necessarily mean that the run did not work.

# Reference Scenario 3 – Schedules

**Instructions: to run the Schedules Scenario, execute run_v6_1.bat in reference_scenarios\rs3_schedules. The run should take about 5-10 minutes. A full description of this scenario is below, including the expected results.**

## Purpose

Scenario 3 increases the complexity of the supply chain by including schedules for each facility. The purpose of this scenario is to demonstrate the movement of one commodity from a single RMP to an intermediate processor facility where the commodity is converted to a new material, and then delivered to a single destination. The three facilities involved each have different schedules impacting how much material is produced, processed, or demanded on a particular day.

## Input Data

FTOT allows for facility schedules using an optional schedules data input file called schedule.csv. The input_data subfolder contains the file. The file specifies a default schedule with full availability every day (default) and three additional schedules, alpha, beta, and gamma, each with varying availability across days:

*Table 2: Reference Scenario 3 schedule input file.*

| schedule | day | availability |
|---|---|---|
| default | 0 | 1 |
| alpha | 0 | 0.5 |
| alpha | 1 | 1.5 |
| beta | 0 | 1 |
| beta | 3 | 0.5 |
| gamma | 0 | 0.75 |
| gamma | 2 | 1 |

The defined schedules for the three facilities can also be represented day-by-day like this:

*Table 3: Day by day representation of schedule input file.*

| schedule | day 1 | day 2 | day 3 |
|---|---|---|---|
| default | 1 | 1 | 1 |
| alpha | 1.5 | 0.5 | 0.5 |
| beta | 1 | 1 | 0.5 |
| gamma | 0.75 | 1 | 0.75 |

The alpha, beta, and gamma schedules are used by the RMP, processor, and destination facilities respectively. This assignment is done through an optional “schedule” column in each respective facility-commodity CSV input file; Figure 6 shows the alpha schedule assignment for the RMP facility. Any facilities not assigned a schedule are assigned the default schedule.

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | facility_name | facility_type | commodity | value | units | phase_of_matter | io | schedule |
| 2 | rmp_25003 | raw_material_producer | blueberries | 100 | tons | solid | o | alpha |

*Figure 6: Scenario 3 raw material producer file containing schedule assignment (rmp.csv).*

## Running a Scenario

The scenario configuration file contains a new field for the schedule data input:

```
2  <Scenario xmlns="Schema_v6.0.0">
3   <Scenario_Schema_Version>6.0.2</Scenario_Schema_Version>
4   <Scenario_Name>Reference Scenario 3: Schedules</Scenario_Name>
-                                          . . .
26    <Schedule_Data>C:\FTOT\scenarios\reference_scenarios\rs3_schedules\input_dat
       a\schedule.csv</Schedule_Data>
-                                          . . .
35  </Scenario_Inputs>
```

The `Schedule_Data` parameter on line 26 points to the location of the schedule file.

The .bat file includes an additional m2 step that creates maps for each day of the scenario. Execute the .bat file in the scenario directory.

## Viewing Results

To quickly check your Scenario 3 results, look for the following lines in the generated report and compare your values to those below. Map outputs in a new folder called “Maps_Time_Commodity” generated by the m2 step visualize optimal supply chain flows for each day of the scenario, adjusted for facility schedules.

```
RESULTS
------------------------------------------------------------------------
...
P_ :  DOLLAR_COST_ALLMODES:      6,849.17 :           USD
...
P_ :  BLUEBERRIES_DOLLAR_COST_ALLMODES:   1,973.11 :     USD
...
P_ :  RMP_25003_RMP_SUPPLY_OPTIMAL_BLUEBERRIES_ROAD:     226.80 :    metric_ton
...
P_ :  DEST_25025_DESTINATION_DEMAND_OPTIMAL_JAM_ALLMODES::    226.80 :   metric_ton
...
```

# Reference Scenario 4 – Disruption

**Instructions: to run the Disruption Scenario, execute run_v6_1.bat in reference_scenarios\rs4_disruption. The run should take no more than a few minutes to complete. A full description of this scenario is below, including the expected results.**

## Purpose

The purpose of the Disruption Scenario is to demonstrate the impact of FTOT disruption (link removal) functionality on the simplest supply chain model (the movement of one commodity from a single origin—or RMP—to a single destination). For more information on FTOT's ability to model scenarios with a disrupted network, consult Section 4 of the FTOT User Guide. While disruption functionality is modeled here in a simple supply chain, disruption can easily be applied to more complex supply chains and FTOT scenarios as well.

## Input Data

The input data in this scenario is a simplified version of Quick Start 1, set in Massachusetts. The geospatial data and facility-commodity data are set up to send 100 tons of blueberries across the state from west to east. There are no intermediate processors in this scenario, and therefore no proc.csv file is needed.

## Running a Scenario

In order to illustrate the effect of disruption to a scenario, this scenario is best compared to a successful run of Quick Start 1, which serves as a baseline (non-disrupted) version of this reference scenario. This reference scenario is a disrupted version of Quick Start 1 in which certain segments on the network are considered unavailable (e.g., due to a crash on the roadway, hazard impact, etc.).

The baseline and disruption scenarios are identical except for two elements. First, in the input_data subfolder of Quick Start 1, only two files are present—rmp.csv and dest.csv. In the input_data subfolder of the disruption reference scenario, a third CSV file is present—disruption.csv. Inside this disruption.csv file is a simple table consisting of three columns—mode, unique_link_id, and link_availability. In this scenario, two unique segments in the FTOT multimodal network are identified—each from the road network. A link_availability of 0 indicates that the segments are to be fully disrupted (completely unavailable for use by the optimization) for the purposes of the FTOT scenario. Note that partial link availability (link_availability values between 0 and 1) is not currently supported by FTOT.

Users with GIS experience can open the road feature class associated with the default FTOT multimodal network in a GIS application and use a Select by Attribute query to highlight the two segments associated with this disruption. These two road segments are highlighted below—they are two critical links along Interstate 90 in central Massachusetts. Details on a supplementary FTOT tool for network disruption that can help generate the disruption.csv file can be found in Section 7 of the User Guide.

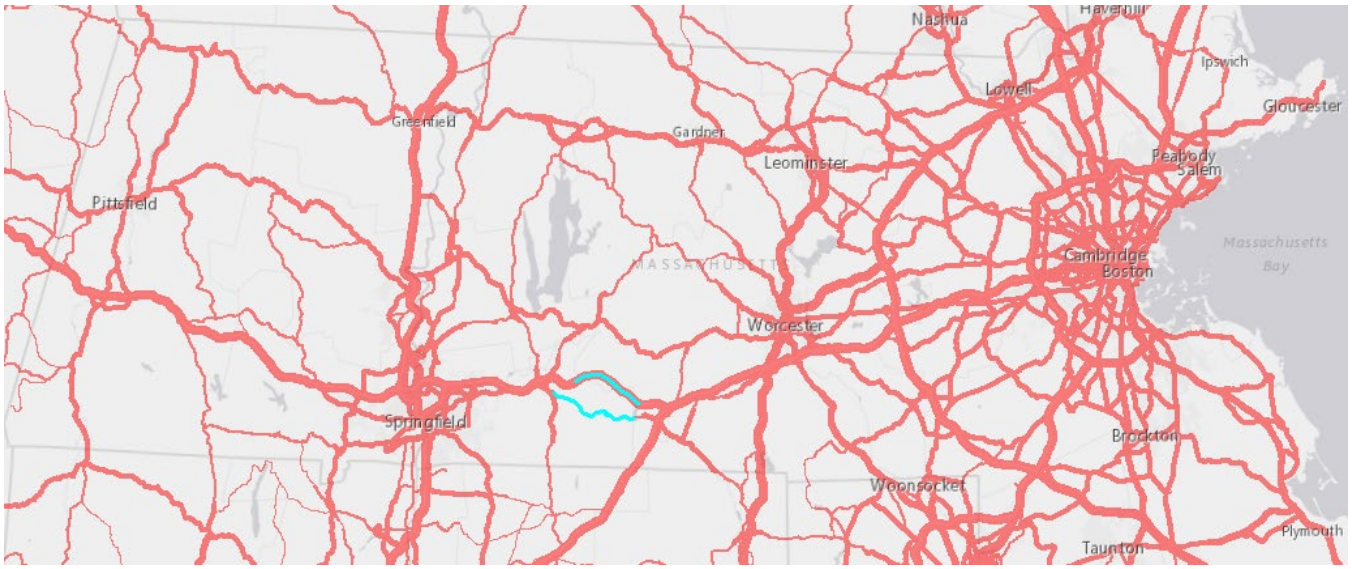


*Figure 7: Scenario 4 disrupted links highlighted.*

In addition, the `Disruption_Data` parameter of the scenario XML file differs between the two scenarios. In the Quick Start 1 scenario, this configuration parameter is set to *None*. This indicates that disruption is not being applied to the scenario. In the reference scenario, this line is populated with the full path to the disruption file described above.

Note that in this scenario, the XML has been set to not permit travel by rail (`Rail` is set to False in the Permitted_Modes section). This ensures that road will be the only viable mode utilized to connect western Massachusetts with eastern Massachusetts.

## Viewing Results

Once each scenario is run, FTOT-generated maps and Tableau provide easy ways to visualize the impact of disruption in this scenario. **For a quick way to compare the two scenarios, for each sub-scenario open 04a_O_Step_Final_Optimal_Routes_With_Commodity_Flow_default_basemap.png.**

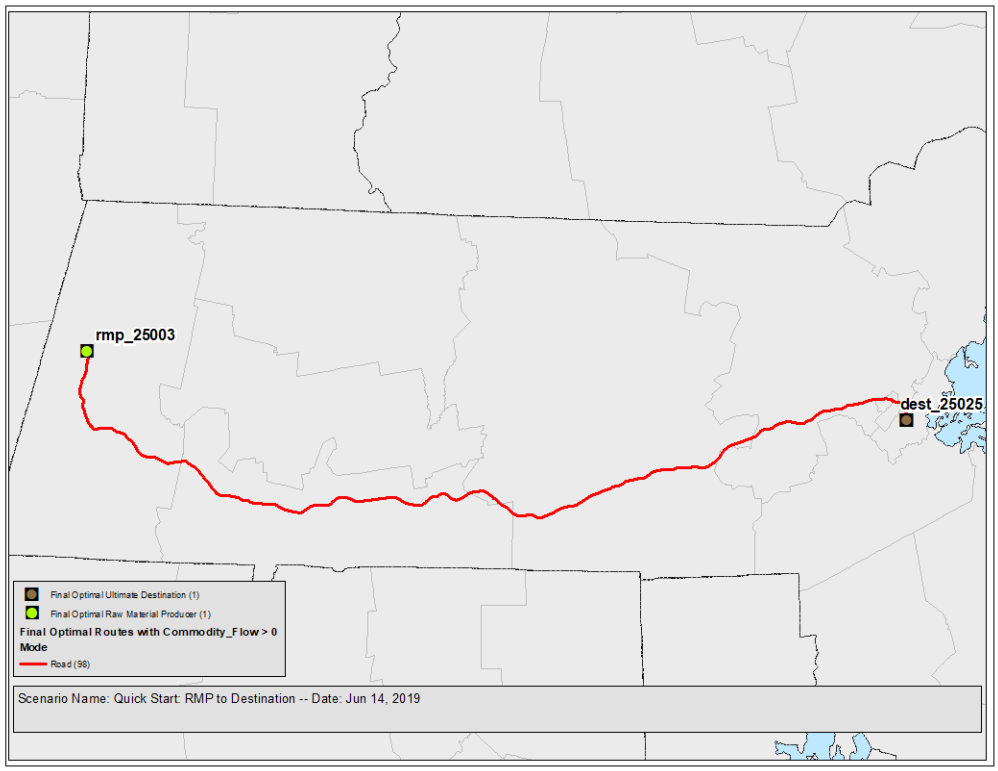


*Figure 8: Baseline scenario (QS1) optimal solution.*

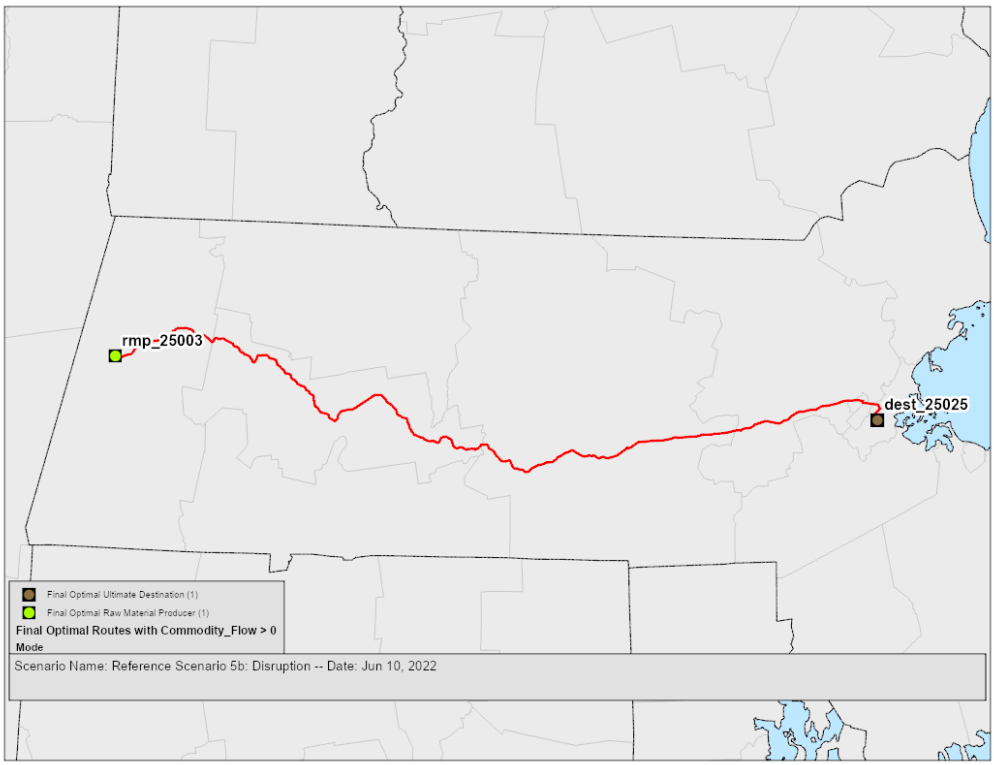


*Figure 9: Disruption scenario (RS4) optimal solution.*

In the Quick Start 1 scenario, the optimal solution shows that material travels over the road network from the RMP to the destination. In this case, the Massachusetts Turnpike (Interstate 90) is used for the majority of the trip. In the disruption reference scenario, a more northerly route off the interstate highway becomes the optimal route. In addition, the disruption scenario has a dollar and routing cost that is greater than the corresponding costs in the baseline scenario, as seen in the text reports.

# Reference Scenario 5 – Network Density Reduction

**Instructions: to run the Network Density Reduction Scenario, execute run_v6_1.bat in reference_scenarios\rs5_network_density_reduction. The run should take between 15-45 minutes. A full description of this scenario is below, including the expected results.**

## Purpose

The purpose of Scenario 5 is to demonstrate a national level RMP to Processor to Destination scenario and the runtime benefits of network density reduction (NDR). NDR can reduce run time for computationally intensive scenarios by identifying minimum cost shortest paths between facilities before solving the optimization problem. Further technical details on NDR can be found in Section 2 of the FTOT Technical Documentation.

## Input Data

The input geospatial and facility-commodity data include many facilities across the continental United States. The RMP CSV file contains 636 facilities supplying a total of 18.7MM tons of commodity A_Supply. There are 20 processors that convert A_Supply into B_Processed. The conversion factor used by each processor is roughly 1 to 1, but the input and output quantities were generated with a random number generator, so conversion efficiency figures vary from facility to facility. The same input quantities are set as the maximum input capacity allowed at each processor, with the minimum input capacity fixed by default at half the maximum, if the facility is used (input for any processor is still allowed to be zero if not used in the optimal solution). The processors have a combined maximum capacity of 59MM tons of input, and maximum output of 49MM tons. A total of 20 destinations, mostly located along the East and West Coasts and Great Lakes region were selected. The destinations demand a total of 33MM tons of commodity B_Processed.

## Running a Scenario

The Scenario 5 scenario XML file sets the Network Density Reduction parameter `NDR_On` to True, and the `Road` field is set to False under the Permitted_Modes section of the Route_Optimization_Script settings.

```
<Route_Optimization_Script>
  <NDR_On>True</NDR_On>
  <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-->
   <Road>False</Road>
   <Rail>True</Rail>
   <Water>True</Water>
   <Pipeline_Crude>True</Pipeline_Crude>
   <Pipeline_Prod>True</Pipeline_Prod>
  </Permitted_Modes>
```

Execute the run.bat file in the scenario directory. The run should take ~15-45 minutes to complete.

## Viewing Results

To quickly check your Scenario 5 results, look for the following lines in the generated text report and compare your values to those below. Users can also compare the maps generated by the run with those in the Map Appendix folder.

Note that 100% of the available RMP supply was utilized and met 60% of the total destination demand, but only 481 of the 636 RMPs were selected as optimal (as listed in the Facility Summary section of the text report). This is due to the fact that some RMPs were not connected to the rail or water networks (and are considered

stranded facilities since road is not a permitted mode). The available A_Supply commodity at these stranded facilities is unable to connect to the FTOT network and reach any destination facility, but stranded facility supply/demand is not included in the utilization calculation.

```
RESULTS
------------------------------------------------------------------
...
O2 :  Optimal Objective Value:  52,888,989,608
...
P_ :      Scenario Total Utilization of Supply and Demand
P_ :      ------------------------------------------------------------------
P_ :      total utilization is defined as (total flow / net available)
P_ :      commodity_name | facility_type | io |  utilization  |   units
P_ :      ---------------|---------------|----|---------------|----------
P_ :      a_supply        raw_material_pr o               1.0 fraction
P_ :      a_supply        processor       i               0.3 fraction
P_ :      b_processed     processor       o               0.5 fraction
P_ :      b_processed     ultimate_destin i               0.6 fraction
P_ :      ------------------------------------------------------------------
...
P_ :  A_SUPPLY_DOLLAR_COST_ALLMODES:                            464,087,826.30 :      USD
...
P_ :  A_SUPPLY_MILES_RAIL:                                      21,482.49:            miles
P_ :  A_SUPPLY_MILES_WATER:                                     2,266.68 :            miles
...
P_ :  B_PROCESSED_MILES_ALLMODES:                               6,369.54 :            miles
...
P_ :  B_PROCESSED_VMT_ALLMODES:                                 120,627,443.08 :      VMT
...
P_ :  PROC_18007_PROCESSOR_INPUT_OPTIMAL_A_SUPPLY_ALLMODES:     4,147,664.06 :        metric_ton
P_ :  PROC_21195_PROCESSOR_INPUT_OPTIMAL_A_SUPPLY_ALLMODES:     731,761.97 :          metric_ton
```

# Reference Scenario 6 – Commodity Mode, Pipelines, and Vehicle Types

**Instructions: Scenario 6 consists of two examples. To run the first example, execute run_v6_1.bat in reference_scenarios\rs6_commodity_mode. The run should take 10-15 minutes. To run the second example, modify the scenario XML file to refer to commodity_mode_2.csv where it refers to commodity_mode.csv, then execute run_v6_1.bat in reference_scenarios\rs6_commodity_mode. A full scenario description for both examples is below, including expected results.**

## Purpose

Scenario 6 demonstrates the use of the commodity mode input file to enable transport by crude and product pipeline networks (Example 1) and to assign custom vehicle types to the road, rail, or water modes (Example 2). Both examples of this scenario also demonstrate detailed emissions reporting, which reflects default or custom vehicle assignments.

## Input Data

For Example 1, the input geospatial and facility-commodity data specify sending 100 kilogallons of crude oil from rmp_40081, near Cushing, Oklahoma, to proc_48201 in Houston, Texas, where it is refined into 100 kilogallons of petroleum products. Of the 100 kilogallons of petroleum products, 10 kilogallons are sent to dest_48453, near Austin, Texas, and 90 kilogallons are sent to dest_34039 in New Jersey.

### Commodity Mode Data

The input_data folder contains a new input file commodity_mode.csv which allows users to assign commodity-specific mode permissions. Crude and product pipeline networks are included in the FTOT network but disabled unless commodity-specific mode permissions are provided, so the commodity mode input file is required if the user wishes to include pipelines in the solution.

The commodity mode input file lists commodities in rows and modes in columns. A "Y" permits a commodity to move by a particular mode[1] while an "N" prohibits it. Note that FTOT allows only liquids to flow by pipeline. The file commodity_mode.csv for Scenario 6 permits crude oil to flow on the crude pipeline network but not the product pipeline network. In contrast, petroleum products can flow on the product pipeline network but not the crude pipeline network.

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

*Figure 10: Scenario 6, Example 1 commodity mode data file (commodity_mode.csv).*

The user can also use the commodity mode input file to assign custom vehicles. In Example 2 of this scenario, the input file commodity_mode_2.csv specifies that petroleum products flowing on the road network will travel by "small_truck" instead of the default truck defined in the scenario XML. Custom vehicles can be created and revised in C:\FTOT\program\lib\vehicle_types.csv.

[1] As long as the scenario XML also sets that mode to True under Permitted_Modes.

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

*Figure 11: Scenario 6, Example 2 commodity mode data file (commodity_mode_2.csv).*

## Emission Factors

Both examples generate a supplementary report with non-$CO_2$ emissions. The input emission factors for different modes, vehicle types, and pollutants are saved in C:\FTOT\program\lib\detailed_emission_factors.csv.

## Running a Scenario

The XML file includes several changes unique to Scenario 6:

- The `Commodity_Mode_Data` file includes the full file path to commodity_mode.csv for Example 1 or commodity_mode_2.csv for Example 2 (once the user has made the instructed edit).
- `Detailed_Emissions_Reporting` is set to True to generate a supplementary report with non-$CO_2$ emissions.
- `Pipeline_Crude_Max_Artificial_Link_Distance` and `Pipeline_Products_Max_Artificial_Link_Distance` are set to 25 miles to allow the county-level points to connect to terminal points on the pipeline network, which is relatively sparse and may not connect to facilities when a smaller artificial link distance is used. The link distance was estimated by measuring the distance from the facility points to a pipeline hub in an ArcGIS application.
- The `Rail` and `Water` fields under Permitted_Modes are set to False to force all commodities to travel by either road or pipeline. Note that setting a mode to False in the XML will apply to all commodities and will override the commodity-specific setting for that mode in the commodity mode data file. More specifically, the "Y" values indicated in the commodity mode input files for both examples for rail and water are overridden by the XML parameters.

```
      <Scenario xmlns="Schema_v6.0.0">

3      <Scenario_Schema_Version>6.0.2</Scenario_Schema_Version>
4      <Scenario_Name>Reference Scenario 6: Commodity Mode, Pipelines, and Vehicle
        Types</Scenario_Name>
_                                          . . .
27      <Commodity_Mode_Data>C:\FTOT\scenarios\reference_scenarios\rs6_commodity_m
         ode\input_data\commodity_mode.csv</Commodity_Mode_Data>
_                                          . . .
35     </Scenario_Inputs>
```

Execute the run.bat file in the scenario directory. Each example run should take 10-15 minutes to complete.

## Viewing Results

To check your Scenario 6 results, look for the following lines in the generated text report and compare your values to those below. Users can also compare the maps generated by the run with those in the Map Appendix folder. In comparing reports for Example 1 and Example 2 below, note the differences in truck loads, vehicle miles traveled, fuel burn, and $CO_2$ emissions for pet_prods traveling by road. These differences are due to the different truck assignments.

Example 1:

Reference Scenario 6 – Commodity Mode, Pipelines, and Vehicle Types

```
RESULTS
------------------------------------------------------------------
...
O2 :  Optimal Objective Value:   23,785
...
P_ :  MILES_PIPELINE_CRUDE_TRF_RTS:         749.14 :             miles
P_ :  MILES_PIPELINE_PROD_TRF_RTS:          1,508.76 :           miles
...
P_ :  PET_PRODS_CO2_ROAD:        279,692.07 :          grams
...
P_ :  PET_PRODS_FUEL_BURN_ROAD:             27.00 :    Gallons
...
P_ :  PET_PRODS_VEHICLES_ROAD:   1.00 :     truck_loads
...
P_ :  PET_PRODS_VMT_ROAD:        199.79 :   VMT
```

Example 2:

```
RESULTS
------------------------------------------------------------------
...
O2 :  Optimal Objective Value:   23,785
...
P_ :  MILES_PIPELINE_CRUDE_TRF_RTS:         749.14 :             miles
P_ :  MILES_PIPELINE_PROD_TRF_RTS:          1,508.76 :           miles
...
P_ :  PET_PRODS_CO2_ROAD:        534,466.18 :          grams
...
P_ :  PET_PRODS_FUEL_BURN_ROAD:             52.84 :    Gallons
...
P_ :  PET_PRODS_VEHICLES_ROAD:   4.00 :     truck_loads
...
P_ :  PET_PRODS_VMT_ROAD:        639.31:    VMT
```

## Detailed Emissions Report

A detailed emissions CSV file in the reports folder summarizes emissions of carbon monoxide (CO), methane ($CH_4$), nitrogen oxides ($NO_x$), volatile organic compounds (VOCs), particulate matter (PM10 and PM2.5), and carbon dioxide equivalents ($CO_2eq$) by commodity and mode. Values depend on emissions factors for associated vehicle types, whether the default vehicle in the XML or a user-created vehicle.

# Reference Scenario 7 – Capacity and Background Flows

**Instructions: to run the Capacity and Background Flows Scenario, execute run_v6_1.bat in reference_scenarios\rs7_capacity. The run should take about 10 minutes. A full description of this scenario is below, including the expected results.**

## Purpose

The purpose of Scenario 7 is to demonstrate FTOT's ability to route commodities based on the daily capacity and existing usage of the transportation network.

## Input Data

Facility data for this scenario are based on a hypothetical freight distribution scenario in New England, transporting bulk freight from a single origin facility to a processor, where it is split into freight parcels for five destination facilities across the region. Goods are only permitted to travel by road in this scenario.

The Capacity_Options section of the scenario XML file is modified to set `Capacity_On` to True (which turns on capacity considerations for all links) and to set Background_Flows for the `Road` network to True (which prompts FTOT to use existing transportation network flows to limit the usable capacity of the road network).

The Capacity_Options section also includes the field `Minimum_Capacity_Level`. When set above 0, this property allows FTOT to flow freight on links that are at or near capacity. In Scenario 7 the `Minimum_Capacity_Level` is 0, meaning that FTOT can only use the currently available capacity of the network and cannot route goods along any link that is over capacity.

## Running a Scenario

The Scenario 7 XML file has several changes from a standard FTOT run in order to support capacity and background flows:

- The `Rail`, `Water`, and `Pipeline` (crude and product) fields are set to False under the Permitted_Modes section of the Route_Optimization_Script settings.
- `Capacity_On` is set to True in the Capacity_Options section of Route_Optimization_Script settings.
- Background_Flows is set to True for `Road` and remains False for all other modes.
- `Minimum_Capacity_Level` is set to 0, meaning that FTOT can only route on links which are not over capacity, and can only route material up to the link's capacity.

The changes to the Capacity_Options section are reproduced below:

```
<Capacity_Options>
  <!--The following 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-->
  <Capacity_On>True</Capacity_On>
  <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-->
    <Road>True</Road>
    <Rail>False</Rail>
    <Water>False</Water>
```

```
            <Pipeline_Crude>False</Pipeline_Crude>
            <Pipeline_Prod>False</Pipeline_Prod>
          </Background_Flows>
          <!--The following setting (0-1) determines the minimum fraction of
            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 traversible in this scenario up to
            the minimum capacity level-->
          <Minimum_Capacity_Level>0.00</Minimum_Capacity_Level>
        </Capacity_Options>
```

The run.bat file uses the “md” command instead of the usual “m” command to show the road network basemap in map outputs.

## Viewing Results

To quickly check your Scenario 7 results, look for the following lines in the generated text report and compare your values to those below. Users can also compare the maps generated by the run with those in the Map Appendix folder.

```
RESULTS
------------------------------------------------------------------------
...
O2 :  Optimal Objective Value: 2,696,711
...
P_ :  FREIGHT_BULK_DOLLAR_COST_ALLMODES:   1,314,467.62 : USD
...
P_ :  FREIGHT_BULK_FUEL_BURN_ROAD:         33,883.39 : Gallons
...
P_ :  DEST_25005_DESTINATION_DEMAND_OPTIMAL_FREIGHT_PARCEL_ROAD:    10,000.00 : ton
```

# Reference Scenario 8 – Scenario Comparison Dashboard

**Instructions: to run the Scenario Comparison Dashboard Scenario, execute the run_v6_1.bat in each of the four subfolders in reference_scenarios\rs8_scenario_compare_dashboard. The runs should take between 7-15 minutes each. After all of the scenarios are complete, concatenate the results using the Scenario Compare Tool in ftot_tools.py. A full description of this scenario is below, including the expected results.**

## Purpose

The purpose of Scenario 8 is to demonstrate how to compare a number of scenarios using the Scenario Compare Tool, which concatenates the data from several scenarios and packages them in a Tableau Workbook.

## Input Data

The Scenario 8 folder contains one scenario XML file for each of the four exercises. The four exercises cover the following scenarios across the United States:

1. A Massachusetts area RMP -> Destination scenario moving blueberries;
2. A Southern California area RMP -> Destination scenario moving agricultural commodities;
3. A Seattle area RMP -> Destination scenario moving plane engines; and
4. An RMP -> Proc -> Destination scenario using crude and product pipelines.

## Running a Scenario

Execute the run.bat files in each of the four exercise subdirectories.

## Scenario Compare Tool

After running all four scenarios, launch FTOT Tools from the command line, and run the Scenario Compare Tool. See Section 7 of the User Guide for step-by-step instructions on running the tool and Section 6 of the User Guide for how to use the comparison dashboard. Specify C:\FTOT\scenarios\reference_scenarios\rs8_scenario_compare_dashboard as the output directory for the comparison dashboard and use recursive search within this directory to concatenate results from all four exercises.

## Viewing Results

Open the newly created tableau_dashboard.twbx comparison dashboard, and explore the results. The tables and charts beneath the map may be especially useful for comparing results across scenarios. For example, the "% Difference" and "Difference" views on the By Commodity & Mode dashboard present each scenario's dollar cost, flow, vehicle miles traveled, fuel burn, and CO2 emissions relative to the scenario from Exercise 1.

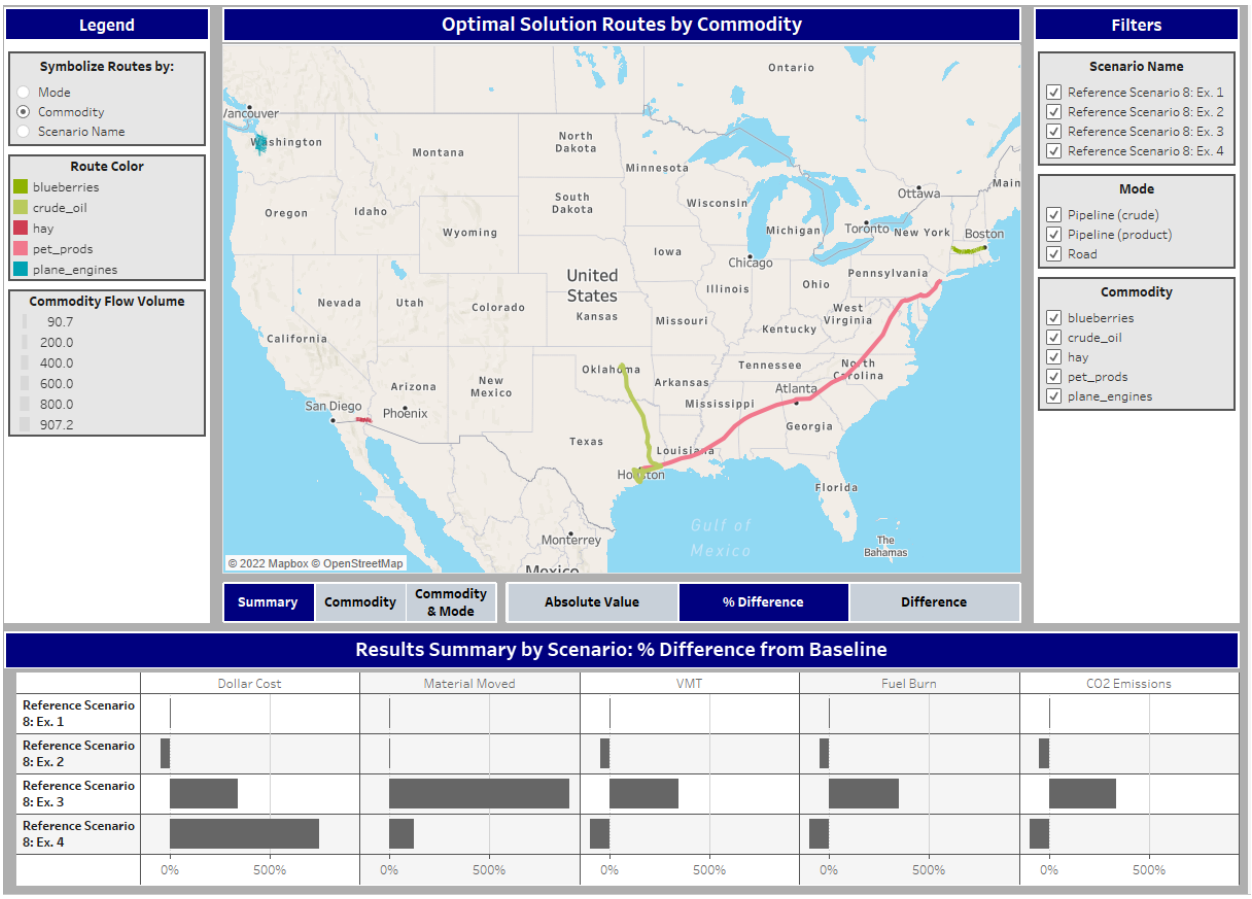


*Figure 12: Scenario comparison dashboard showing all four exercises and their percent difference in scenario results.*

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