Freight and Fuel Transportation Optimization Tool Reference Scenarios Documentation

FTOT 2025.3 Public Release Version

September 30, 2025

DOT-VNTSC-FAA-22-09 Rev. 13

DOT/FAA/AEE/2022-04 Rev. 13

Prepared for:

Federal Aviation Administration
Office of Environment and Energy
Washington, DC

U.S. Department of Transportation
John A. Volpe National Transportation Systems Center

Notice

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 30, 2025	Document, 7/2022-9/2025

4. TITLE AND SUBTITLE Freight and Fuel Transportation Optimization Tool Reference Scenarios Documentation: FTOT 2025.3 Public Release Version	5a. FUNDING NUMBERS FC14C222 FC14C323 FC14CA24
6. AUTHOR(S) Olivia Gillham, Kirby Ledvina, Kristin C. Lewis (PM), Mark Mockett, Matthew N. Pearlson, Peter Wilke, Jaewoong Yun, Kevin Zhang	5b. CONTRACT NUMBER 693KA9-22-T-00008 693KA9-23-T-00005 693KA9-24-T-00002
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Volpe National Transportation Systems Center, 220 Binney Street, Cambridge, MA 02142	8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FAA-22-09 Rev. 13
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Federal Aviation Administration, 800 Independence Ave, SW, Washington, DC 20591	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FAA/AEE/2022-04 Rev. 13

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

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 2025.3. This documentation is updated quarterly and available on the Public FTOT GitHub repository: https://github.com/VolpeUSDOT/FTOT-Public

14. SUBJECT TERMS Freight, fuel, geospatial information systems, GIS, network analysis, transportation optimization.	15. NUMBER OF PAGES 38
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

298-102

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 containing the Reference Scenarios files should look like this:

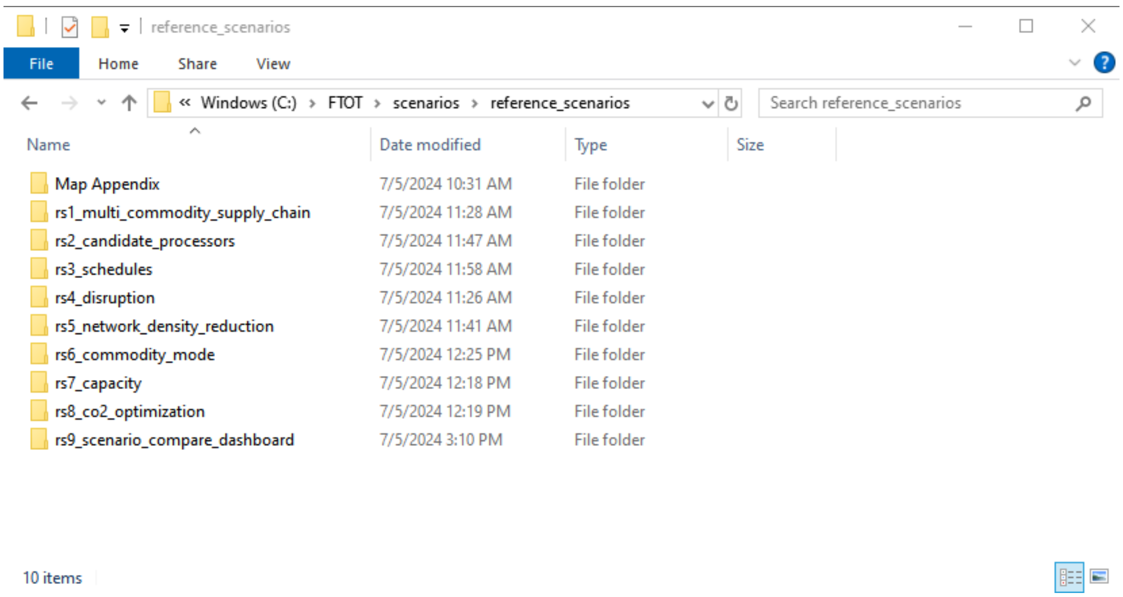


Figure 1: FTOT reference scenarios folder structure.

The Reference Scenarios series is a set of FTOT scenarios each designed to demonstrate how to configure different aspects 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(s) and input files as a starting point. If developing custom scenarios from these templates, refer to the User Guide for more guidance. The nine 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; processor facility capacity; network density reduction (NDR) pre-solve method; unmet demand penalties; custom artificial link costs
2	*Candidate processing facilities*	FTOT-generated candidate processors; pre-determined candidate processors; NDR pre-solve method
3	*Facility schedules*	Schedules; maps by time period and commodity; NDR pre-solve method; solver options
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
8	*CO_2-based optimization*	Routing optimization incorporating emissions costs
9	*Scenario comparisons*	Generating scenario comparison dashboard; routes storypoint in Tableau 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(s) 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.
- Several scenarios include optional exercises that provide the user with more interactive examples of different FTOT functionalities. These exercises ask the user to edit specified FTOT input files, run the new scenario, and compare the results with the baseline reference scenario.
- 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\Default) contains a batch script file called **run_vX.bat**, where the X denotes the version number of the latest XML schema.
- 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 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: runtime 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 a timestamped folder within 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. If the user chooses to generate time period and commodity specific maps using the m2 step, these map files can be found in a timestamped folder within the **.\Maps_Time_Commodity** directory of 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 runs 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_v8.bat in reference_scenarios\rs1_multi_commodity_supply_chain\Default. The run should take between 5-10 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 various methods for setting facility capacity for processing facilities.

KEY CONCEPTS:

- Multiple processing steps
- Multi-input processors
- Multi-output processors
- Processor facility capacity
- Unmet demand penalty
- Custom artificial link costs

KEY FILE(S) IN FOLDER:

- rmp.csv
- proc.csv
- dest.csv

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 boxes and apple butter, (3) a canning facility that converts apple butter to canned apple butter. 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 input. The maximum total processor input is set to 150 tons by including a row with commodity "total" and io value "i" with a max_capacity column specifying 150 tons. There is no min_capacity column specified, so the minimum total processor input is set to zero tons. In general, the minimum capacity is adjustable by the user as well by including a min_capacity column in the proc.csv input file (see Section 3.3 of the FTOT User Guide for more information). Capacity restrictions apply to the commodity or total row they are listed on. Maximum and minimum capacity values may be entered by the user for any commodity, as well as by a "total" row; all are checked, and the most restrictive capacity constraint is applied. In this case, the total processor input capacity means a maximum of 75 tons for each of blueberries and sugar since they are input in a 1:1 ratio. Note that FTOT requires all of a processor's input 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_boxes and 75 tons of apple_butter, with a maximum output of 75 tons apple_butter. This is equivalent to a total maximum processor output of 150 tons (or total maximum processor input of 200 tons). Finally, proc_25009 converts 100 tons of apple_butter to 100 tons of canned_apple_butter, with a total maximum processor input of 150 tons apple_butter. Note how FTOT uses the distinct names of commodities 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 Default 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.

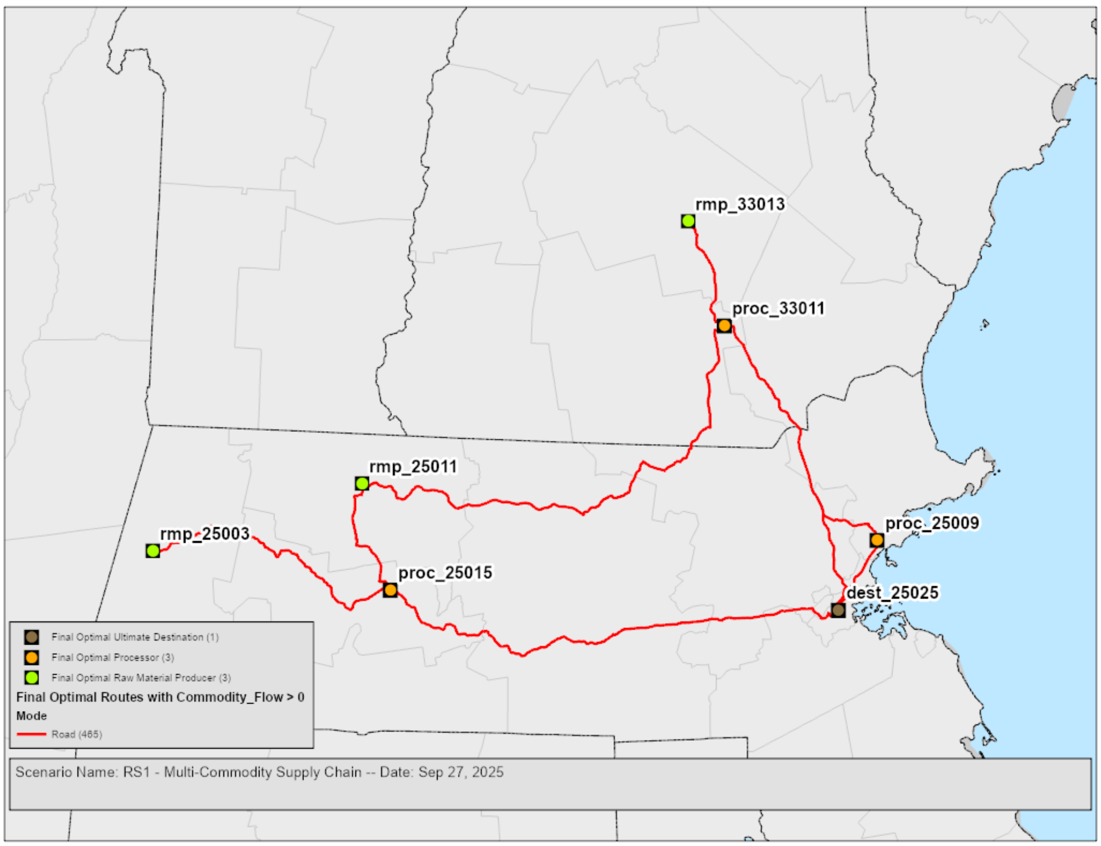


Figure 2: Scenario 1 multi-commodity supply chain optimal solution map.

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 boxes 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.

Optional Exercises – Unmet Demand Penalties (UDP) and Access Costs

These exercises demonstrate two optional columns that may be added to the input facility-commodity data files:

1) The first optional column, "udp", is specific to the destination input file (e.g., dest.csv). Short for unmet demand penalty, the "udp" column allows a facility and/or commodity specific customization of penalties for destination facilities that do not meet their demand. A higher penalty given to a destination facility-commodity pair prioritizes meeting demand for that commodity at that facility. The "udp" value is specified as a penalty per commodity unit defined in the "units" column. When there is no "udp" column, FTOT uses the default UDP specified in the scenario XML file for all commodities and destinations (specified as a penalty per default solid unit as defined in the scenario XML file).

   For this exercise, the user will add an optional UDP column, as shown in Figure 3 below. Note that the highlighted cells represent additions to the original destination input file for the purpose of this exercise. To start, refer to the scenario in the directory: C:\FTOT\scenarios\reference_scenarios\rs1_multi_commodity_supply_chain\Exercise 1.

facility_name	facility_type	commodity	value	units	phase_of_matter	io	udp
dest_25025	ultimate_destination	blueberry_jam	100	tons	solid	i	3000
dest_25025	ultimate_destination	apple_juice	75	tons	solid	i	5000
dest_25025	ultimate_destination	canned_apple_butter	75	tons	solid	i	
dest_25001	ultimate_destination	canned_apple_butter	75	tons	solid	i	10000

Figure 3: Scenario 1 Exercise 1 destination file (dest.csv).

   Set values in the "udp" column for each facility-commodity row as shown in Figure 3. In addition, add a new destination facility for canned apple butter. Set a higher UDP for this destination, dest_25001, to indicate that demand for 75 tons of canned apple butter at dest_25001 is prioritized over demand for canned apple butter at dest_25025 during the optimization process. The blank "udp" cell for dest_25025 is set to the default UDP value (e.g., 5000 per ton) in the scenario XML file. Save the file and execute the run.bat file in the Exercise 1 directory.

   The final output CSV report (Figure 4) displays the following metrics, detailing optimal fulfillment of canned apple butter at dest_25001 instead of dest_25025, despite the latter being closer to the processing facilities.

208	RS1 - Multi-Commodity Supply Chain	facility_summary	canned_apple_butter	dest_25001	destination_demand_optimal	allmodes	75	ton
209	RS1 - Multi-Commodity Supply Chain	facility_summary	canned_apple_butter	dest_25001	destination_demand_optimal	road	75	ton
210	RS1 - Multi-Commodity Supply Chain	facility_summary	canned_apple_butter	dest_25001	destination_demand_optimal_frac	allmodes	1	fraction
211	RS1 - Multi-Commodity Supply Chain	facility_summary	canned_apple_butter	dest_25001	destination_demand_optimal_frac	road	1	fraction
212	RS1 - Multi-Commodity Supply Chain	facility_summary	canned_apple_butter	dest_25001	destination_demand_potential	total	75	ton
213	RS1 - Multi-Commodity Supply Chain	facility_summary	canned_apple_butter	dest_25025	destination_demand_potential	total	75	ton

Figure 4: Scenario 1 Exercise 1 CSV report.

2) The second optional column, "access_cost", is a column that can be added to any facility-commodity input CSV file besides proc_cand.csv. The access cost is a customizable value that allows the user to add a separate cost on artificial links at a facility, commodity phase, and/or input/output level. For example, if a feedstock location is particularly remote, the user may specify a higher access cost for this facility to reflect the increased difficulty of navigation to the closest network link or any other specific cost factors associated with material coming out of this location.

   In the second exercise, the user will add access costs in a new column for raw material producers. For this exercise, refer to the directory: C:\FTOT\scenarios\reference_scenarios\rs1_multi_commodity_supply_chain\Exercise 2.

facility_name	facility_type	commodity	value	units	phase_of_matter	io	access_cost
rmp_25003	raw_material_producer	blueberries	100	tons	solid	o	25
rmp_25011	raw_material_producer	sugar	200	tons	solid	o	20
rmp_33013	raw_material_producer	apples	75	tons	solid	o	15
rmp_33019	raw_material_producer	apples	25	tons	solid	o	30

Figure 5: Scenario 1 Exercise 2 raw material producer file (rmp.csv).

Update the rmp.csv file as indicated by the highlighted cells in Figure 5. Facility rmp_33019, located on a mountainous unpaved road, has higher transport costs due to the reduced convenience compared to facility rmp_33013, which is more accessible to the nearest road. Set a higher access cost for rmp_33019 to indicate apples are easier to source from facility rmp_33013 instead. The access costs are not input as per-mile transportation costs on the artificial link, but per commodity unit as specified in the "units" column (e.g., per ton). Different commodities from the same facility may have different access costs if they are different phases of matter. If the "access_cost" column is omitted, access costs are not considered in the FTOT scenario.

To view changes in the optimal results, check the report CSV file. Access costs are reported by facility and commodity, as well as in aggregate. In addition, a higher routing cost per ton is reported for facility-commodity pairs that had higher access costs.

Reference Scenario 2 - Candidate Processor Generation

Instructions: to run the Candidate Processor Generation Scenario, execute run_v8.bat in reference_scenarios\rs2_candidate_processors. The run should take about 10-20 minutes with NDR enabled, or 3-4 hours without NDR. 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.

KEY CONCEPTS:

- FTOT-generated candidate processors
- Pre-determined candidate processors
- Processor build costs
- Maximum transport distance

KEY FILE(S) IN FOLDER:

- proc_cand.csv

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 6). 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 65 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	65
3	rmp_25013	raw_material_producer	blueberries	70	tons	solid	o	65

Figure 6: 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 blueberries to jam in a 1 to 1 ratio, with a minimum processor size of 50 tons and maximum size of 100 tons. 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, 8 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	8	USD/ton		
7	candidate_jammery	processor	min_aggregation	10	ton	solid	

Figure 7: 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 the 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 30 USD, making it less expensive per ton than the FTOT-generated candidate processors. Note that since minimum capacity is not specified, the minimum operating capacity of the processor is set to the default of zero tons.

	A	B	C	D	E	F	G	H	I
1	facility_name	facility_type	commodity	value	units	phase_of_matter	io	max_capacity	build_cost
2	proc_25015	processor	blueberries	100	tons	solid	i	80	30
3	proc_25015	processor	jam	100	tons	solid	o		30

Figure 8: 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 candidate processors.

The scenario XML file sets the NDR_On parameter to True to reduce the runtime of the scenario from 3-4 hours to less than 20 minutes. If the user wishes to run this scenario with NDR_On set to False, the user should update the max_transport_distance parameter to 120 miles to account for a known issue with how the maximum transport distance is applied to the network. Results for candidate generation scenarios may differ when NDR is or is not enabled since the methods are distinct; further details on this distinction can be found in Section 2.4 of the technical documentation.

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:   3,567
...
O2 :  Optimal Objective Value:   5,039
...
P_ :  BLUEBERRIES_TRANSPORT_COST_ALLMODES:            968.95 :   usd
...
P_ :  CANDIDATE_JAMMERY_95233_PROCESSOR_INPUT_OPTIMAL_BLUEBERRIES_ALLMODES:           100.00 :    ton
P_ :  PROC_25015_PROCESSOR_INPUT_OPTIMAL_BLUEBERRIES_ALLMODES:    60.00 :    ton
```

Reference Scenario 3 – Schedules

Instructions: to run the Schedules Scenario, execute run_v8.bat in reference_scenarios\rs3_schedules\Default. 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 a different schedule impacting how much material is produced, processed, or demanded on a particular day, which leads to storage of commodities at facilities across time periods.

KEY CONCEPTS:

- Raw material production schedules
- Processing schedules
- Destination demand schedules
- Facility storage
- Time periods
- Solver options

KEY FILE(S) IN FOLDER:

- schedule.csv

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 as shown in Table 2 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 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 9 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 9: 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:

```
1   <Scenario xmlns="Schema_v8.0.0">
2    <Scenario_Schema_Version>8.0.1</Scenario_Schema_Version>
3    <Scenario_Name>RS3 - Schedules</Scenario_Name>
-                                . . .
26     <Schedule_Data>C:\FTOT\scenarios\reference_scenarios\rs3_schedules\Default\i
       nput_data\schedule.csv</Schedule_Data>
-                                . . .
37   </Scenario_Inputs>
```

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

Note that the scenario configuration file also has NDR enabled and has set the solver used to HiGHS, instead of the default CBC solver.

Execute the run.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.

```
RESULTS
---------------------------------------------------------------------
...
P_ :  TRANSPORT_COST_ALLMODES:   5,799.18 :            usd
...
P_ :  BLUEBERRIES_TRANSPORT_COST_ALLMODES:   2,147.41 :     usd
...
P_ :  DEST_25025_DESTINATION_DEMAND_OPTIMAL_JAM_ALLMODES:    225.00 :   ton
...
P_ :  RMP_25003_RMP_SUPPLY_OPTIMAL_BLUEBERRIES_ROAD:     225.00 :    ton
...
```

The "By Commodity & Mode" dashboard in the tableau_dashboard.twbx output file (Figure 10) maps the optimal flow. Select or deselect time periods from the filter on the right side of this dashboard to view results aggregated across different periods. Note that the time period filter affects only the map on this dashboard. The filter does not affect the tables beneath the map (not shown). If enabled, the M2 step for time period and commodity specific mapping outputs maps in the scenario's .\Maps_Time_Commodity folder to show optimal flows for each time step in the schedule.

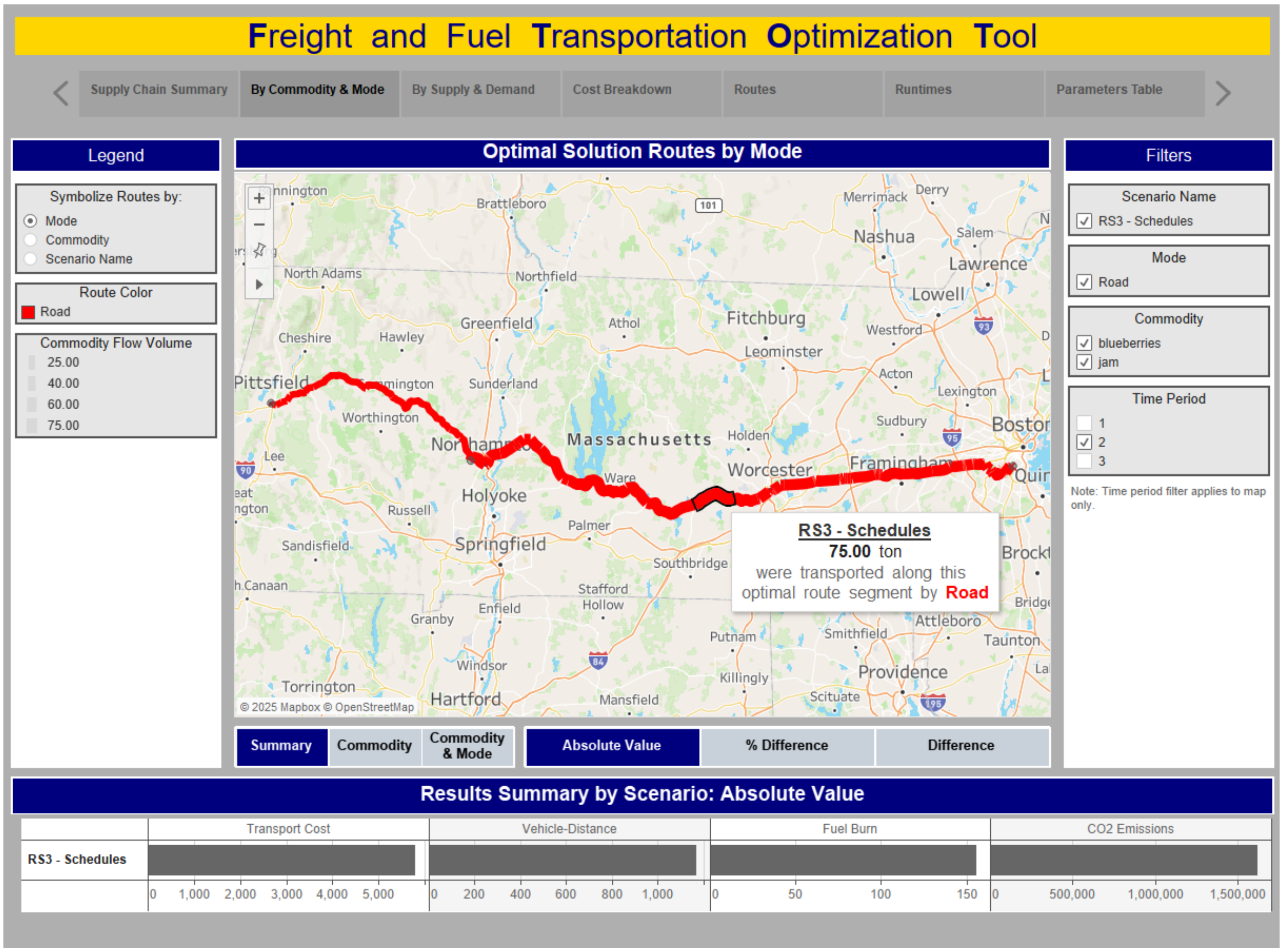


Figure 10: Scenario 3 "By Commodity & Mode" Tableau dashboard with time period filtering (filtered to show time period 2 results).

Using the Tableau dashboard, the user can see that the total amount of material transported through the entire scenario is 225 tons. If the user unchecks time periods 2 and 3, leaving only time period 1 checked, the user can see that 150 tons of blueberries are transported from the RMP facility to the processing facility during time period 1. However, only 75 tons of jam are delivered to the destination facility during time period 1 due to the destination operating at 75% availability as defined in the schedule CSV file. The remaining 75 tons are stored at the processing facility for the next day.

If user filters the dashboard for time period 2, the user can see that 25 tons of blueberries are sent from the RMP facility to the processing facility during that time period 2, but only the 75 tons that were stored from time period 1 are sent to the destination facility.

For time period 3, 50 tons of blueberries are sent to the processing facility. All of this raw material, plus 25 tons from time period 2, is processed into jam and sent to the destination facility.

Optional Exercises – Solver Options

The exercise demonstrates how users can configure the FTOT optimization step to switch the solver package used and to set a time limit to exit out of the optimization process early, potentially before the routing solution has been proven to be optimal.

In the C:\FTOT\scenarios\reference_scenarios\rs3_schedules\Exercise directory, the scenario XML file has been modified to disable network density reduction (NDR) as seen below. This increases the runtime of this scenario to 2-3 hours to find the same optimal routing solution discussed above.

```
1    <Scenario xmlns="Schema_v8.0.0">
2     <Scenario_Schema_Version>8.0.1</Scenario_Schema_Version>
3     <Scenario_Name>RS3 - Schedules</Scenario_Name>
-                                   . . .
116    <NDR_On>False</NDR_On>
-                                   . . .
143    <Solver_Options>
144     <!-- Specify the default solver, COIN-OR Branch-and-Cut (CBC) using
         either "Default" or "CBC". -->
145     <!-- Specify an alternate solver, HIGHS, using "HIGHS" - all other
         solvers must be configured in ftot_pulp.py. -->
146     <Solver>HIGHS</Solver>
147     <!-- To specify a time limit, use a number and a unit of time, e.g.
         "30 seconds" or "1.5 hours". Mixing time units (e.g. "1 hour and 30
         minutes" is not allowed.-->
148     <Solver_Time_Limit>None</Solver_Time_Limit>
149    </Solver_Options>
```

To force the optimization solver to terminate early, the user can adjust the Solver_Time_Limit parameter in the scenario XML file (line 148). Specifying a time limit will cause FTOT to report out the best routing solution found by the solver within the time limit even if no solution has been proven to be optimal at that time. If using this solver functionality, the user should be cautious; setting too short of a time limit can lead to a significantly sub-optimal solution for the FTOT scenario. This feature is best used for large-scale scenarios that do not solve after several hours or days. Setting a time limit of two to six hours will allow the user to produce a solution and generate the standard FTOT outputs. When setting a time limit, the user should always the optimization log files to confirm the quality of their routing solution.

For this exercise, try setting the Solver_Time_Limit to a couple of different values (e.g., "15 minutes", "1 hour"). Run FTOT using the batch file in the C:\FTOT\scenarios\reference_scenarios\rs3_schedules\Exercise directory. To determine whether the solver terminated with an optimal solution, refer to the "probsolve_capture.txt" file in the "debug" folder, which reports the solver status and optimality gap at the solver's termination. If the solver finished without finding a provably optimal solution, the status will indicate the time limit has been reached.

Below are results for sample runs where the time limit was set to 15 minutes and 1 hour, respectively. Note: The user's outputs may vary depending on the time limit they set and their hardware specifications.

No routing solution is found at 15 minutes as seen by the "no flow" solution reported in the text report since the solver timed out before getting near the optimal solution. Looking at the "probsolve_capture.txt" report, the gap from optimal is still 99.42%, which is significantly higher than the threshold of 0.01% needed to consider a solution to be optimal.

In the 1 hour scenario run, the solver successfully found the same optimal solution that was found when no time limit was set (e.g., when allowed to run for 2-3 hours). This behavior can occur since the solver aims to prove optimality—the correct solution may be found earlier in the process, but the remainder of the solver's time is spent proving that no other possible solutions are better (e.g., note that the gap from optimal is still very significant).

```
RESULTS
---------------------------------------------------------------------
...
P_ :  TRANSPORT_COST_ALLMODES:   5,799.18 :           usd
...
P_ :  BLUEBERRIES_TRANSPORT_COST_ALLMODES:   2,147.41 :     usd
...
P_ :  DEST_25025_DESTINATION_DEMAND_OPTIMAL_JAM_ALLMODES:    225.00 :   ton
...
P_ :  RMP_25003_RMP_SUPPLY_OPTIMAL_BLUEBERRIES_ROAD:     225.00 :    ton
...
```

Reference Scenario 4 – Disruption

Instructions: to run the Disruption Scenario, execute run_v8.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.

KEY CONCEPTS:

- Network disruption / link removal
- Scenario comparison

KEY FILE(S) IN FOLDER:

- disruption.csv

Input Data

The input data in this scenario resembles 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 on 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, four unique segments in the default 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 four segments associated with this disruption. These four road segments are highlighted below—they are three critical links along Interstate 90 and one link on a parallel road 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.

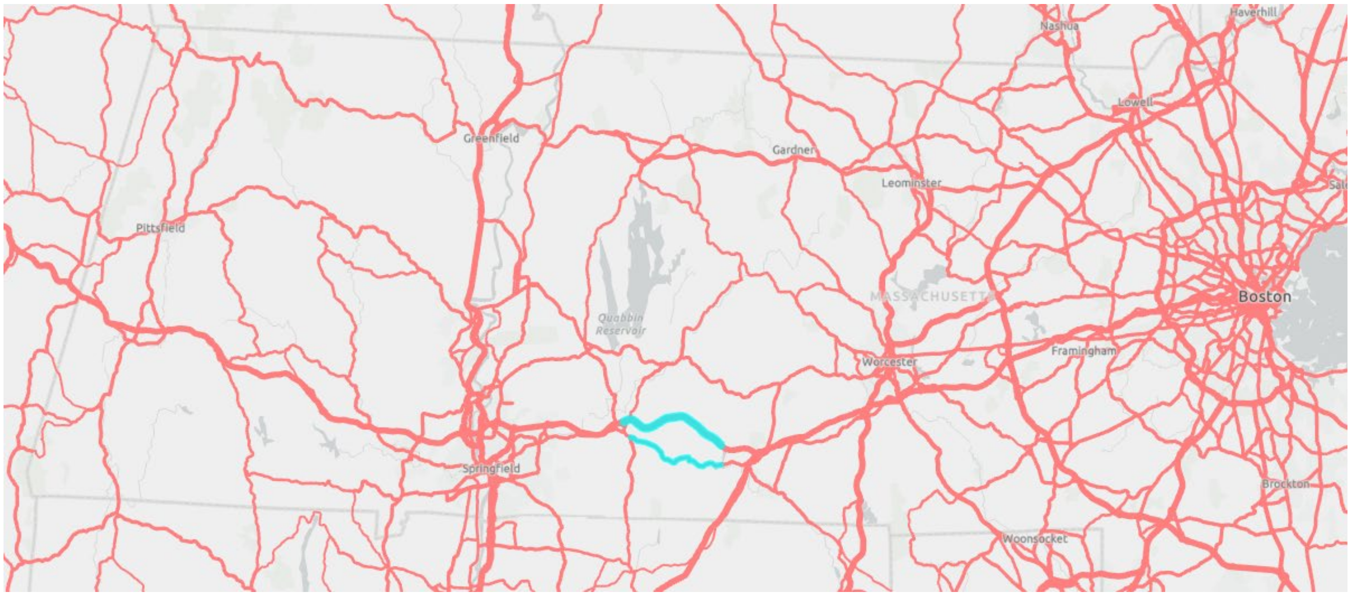


Figure 11: Scenario 4 disrupted links highlighted.

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 scenario open 04a_O_Step_Final_Optimal_Routes_With_Commodity_Flow_default_basemap.png.**

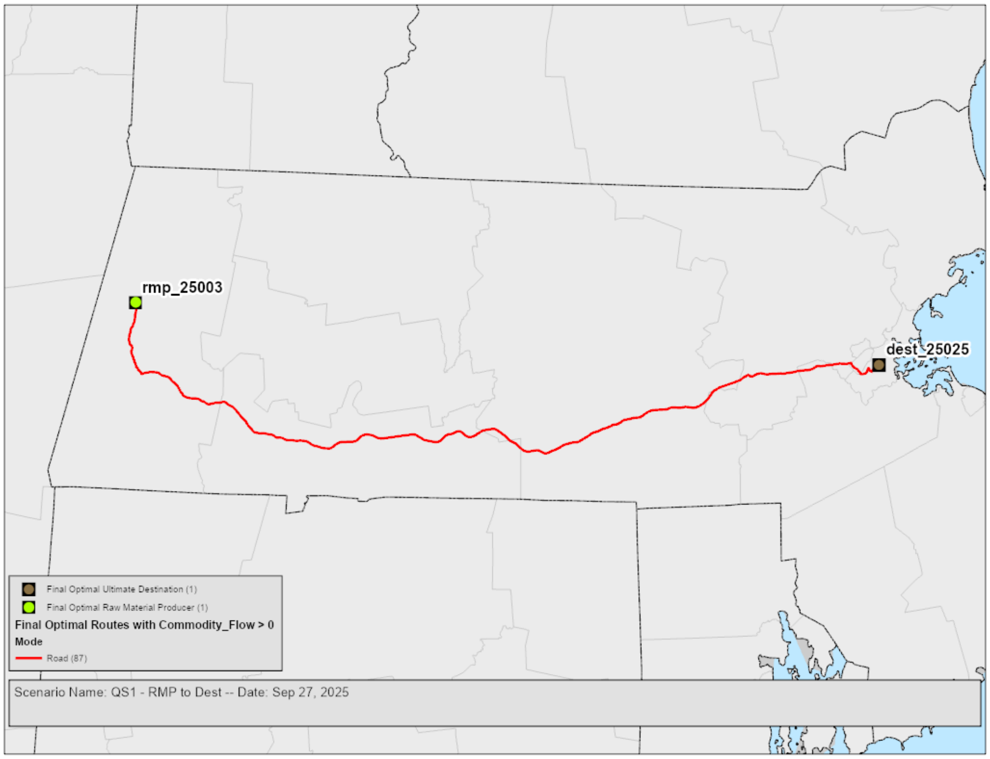


Figure 12: Baseline scenario (QS1) optimal solution.

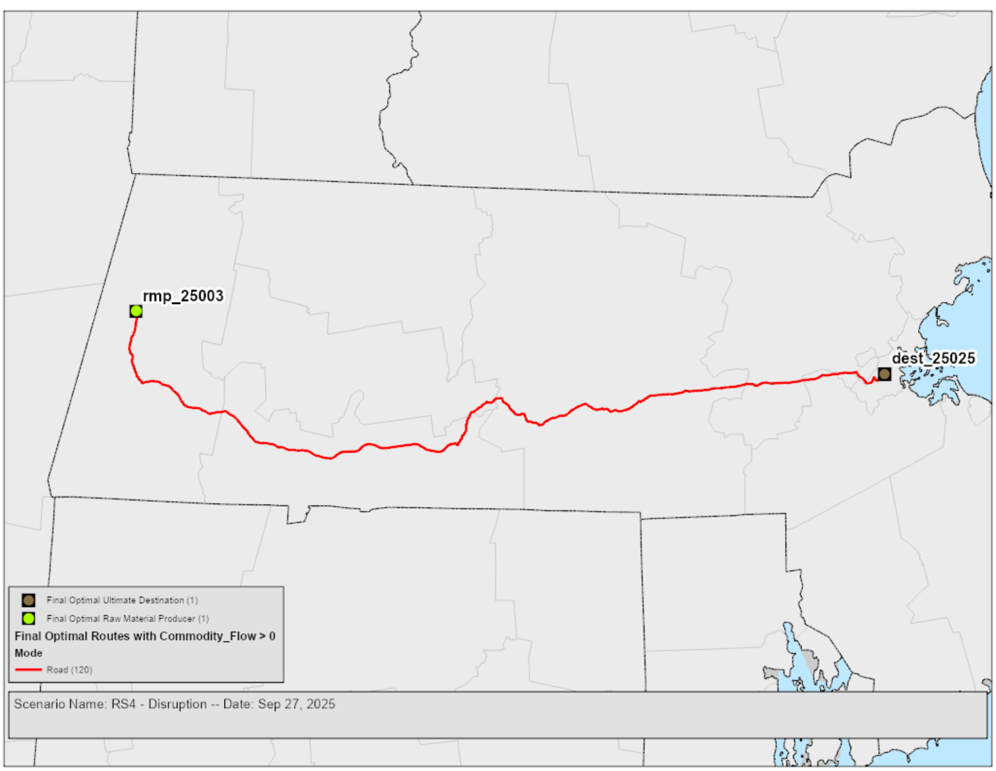


Figure 13: Disruption scenario (RS4) optimal solution.

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, the optimal route takes a detour on local roads in the middle of the route to avoid the disruption on the interstate highway. In addition, the disruption scenario has a transport and routing cost that is greater than the corresponding costs in the baseline scenario, as seen in the text reports.

Since these two FTOT scenarios were run with the 'NDR_On' parameter set to True in the scenario XML, supplementary reports that facilitate route-level comparisons of cost, distance, and travel time were generated in the Reports folders with filenames starting with "all_routes". The optimal route in the Quick Start 1 scenario is approximately 134.8 miles long with an estimated travel time of 2.2 hours, while the optimal route in the disruption scenario is approximately 139.1 miles long with an estimated travel time of 2.5 hours due to fewer interstates. See Reference Scenarios 2 and 5 for further demonstrations of the Network Density Reduction (NDR) functionality.

Reference Scenario 5 – Network Density Reduction

Instructions: to run the Network Density Reduction Scenario, execute run_v8.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 runtime 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.

KEY CONCEPTS:

- Network density reduction
- Runtime improvements
- National supply chains
- Permitted modes

KEY FILE(S) IN FOLDER:

- None

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 specified 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 input 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 99% of the available RMP supply was utilized and met 62% of the total destination demand, but only 466 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.

Since NDR was enabled, Scenario 5 results also include a CSV report on shortest path routes between facilities, including those used in the optimal solution. The report indicates the origin and destination facility types, the commodity and phase of matter flowed on the route, mode, length, transport cost per unit of commodity flowed, routing cost per unit of commodity flowed, access cost per unit of commodity flowed, estimated route travel time, and CO_2 emissions per unit of commodity flowed for each of the 8,245 routes linking an RMP to a processor or a processor to a destination. The report also indicates in the "in_solution" column whether the route was used in the optimal solution or not. Since transport costs differ by phase of matter (e.g., solid, liquid), the corresponding shortest path route between two facilities may differ. However, all commodities in this scenario are solids, so there is exactly one shortest path route between each pair of facilities.

```
RESULTS
---------------------------------------------------------------------
...
O2 :  Optimal Objective Value:  59,560,832,925
...
P_ :      Scenario Total Utilization of Supply and Demand
P_ :      ------------------------------------------------------------------
P_ :      note: 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               0.99 fraction
P_ :      a_supply        processor       i               0.25 fraction
P_ :      b_processed     processor       o               0.50 fraction
P_ :      b_processed     ultimate_destin i               0.62 fraction
P_ :      ------------------------------------------------------------------
...
P_ :  A_SUPPLY_NETWORK_USED_RAIL:                               22,112.62 :           mile
P_ :  A_SUPPLY_NETWORK_USED_WATER:                              2,078.60 :            mile
...
P_ :  A_SUPPLY_TRANSPORT_COST_ALLMODES:                          436,243,376.84 :     usd
...
P_ :  B_PROCESSED_NETWORK_USED_ALLMODES:                         6,321.36 :           mile
...
P_ :  B_PROCESSED_VEHICLE-DISTANCE_TRAVELED_ALLMODES:            97,491,151.85 :      vehicle-mile
...
P_ :  PROC_18007_PROCESSOR_INPUT_OPTIMAL_A_SUPPLY_ALLMODES:      4,710,648.00 :       ton
...
P_ :  PROC_41027_PROCESSOR_INPUT_OPTIMAL_A_SUPPLY_ALLMODES:      865,181.00 :         ton
```

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

Instructions: To run the default scenario, execute run_v8.bat in reference_scenarios\rs6_commodity_mode\Default. The run should take 10-15 minutes. A full scenario description is below, including expected results.

Purpose

Scenario 6 demonstrates the use of the commodity mode input file to enable transport by crude and petroleum product pipeline networks. This scenario also demonstrates detailed emissions reporting, which reflects default or custom vehicle assignments.

KEY CONCEPTS:

- Crude and product pipelines
- Artificial links
- Commodity-specific mode permissions
- Custom vehicle types
- Detailed emissions reporting

KEY FILE(S) IN FOLDER:

- commodity_mode.csv
- vehicle_types.csv *(in program/lib folder)*
- detailed_emissions_factors.csv *(in common_data/networks folder)*

Input Data

The input geospatial and facility-commodity data specify sending 100 thousand gallons of crude oil from rmp_40081, near Cushing, Oklahoma, to proc_48201 in Houston, Texas, where it is refined into 100 thousand gallons of petroleum products. Of the 100 thousand gallons of petroleum products, 10 thousand gallons are sent to dest_48453, near Austin, Texas, and 90 thousand gallons 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 petroleum 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 (as long as the scenario XML also sets that mode to True under Permitted_Modes) 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 petroleum product pipeline network. In contrast, petroleum products can flow on the petroleum product pipeline network but not the crude pipeline network.

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

Figure 14: Scenario 6 commodity mode data file (commodity_mode.csv).

Emissions Factors

Scenario 6 generates a supplementary report with non-CO_2 emissions. The input emissions factors for different modes, vehicle types, and pollutants are saved in detailed_emissions_factors.csv in the networks subfolder of common_data.

Running a Scenario

The XML file includes several changes unique to Scenario 6:

- The `Commodity_Mode_Data` parameter is specified as the full file path to commodity_mode.csv. `Detailed_Emissions_Data` contains the file path to detailed_emissions_factors.csv to generate a supplementary emissions report with both CO_2 and 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, if there were "Y" values indicated in the commodity mode input files for rail or water, they would be overridden by the XML parameters.

```
<Scenario xmlns="Schema_v8.0.0">

  <Scenario_Schema_Version>8.0.1</Scenario_Schema_Version>
  <Scenario_Name>RS6 - Commodity Mode, Pipelines, and Vehicle
   Types</Scenario_Name>
                              . . .
    <Commodity_Mode_Data>C:\FTOT\scenarios\reference_scenarios\rs6_commodity_m
     ode\Default\input_data\commodity_mode.csv</Commodity_Mode_Data>
                              . . .
  </Scenario_Inputs>
```

Execute the run.bat file in the scenario directory. The 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.

```
RESULTS
---------------------------------------------------------------------
...
O2 :  Optimal Objective Value:   24,609
...
P_ :  NETWORK_USED_PIPELINE_CRUDE_TRF_RTS:           577.07:             mile
P_ :  NETWORK_USED_PIPELINE_PROD_TRF_RTS:   1,500.04 :           mile
...
P_ :  PET_PRODS_CO2_ROAD:        490,837.37:           grams
...
P_ :  PET_PRODS_FUEL_BURN_ROAD:             47.60:     Gallons
...
P_ :  PET_PRODS_VEHICLE-DISTANCE_TRAVELED_ROAD:       348.75 :   vehicle-mile
...
P_ :  PET_PRODS_VEHICLES_ROAD:   12.50 :     truck_loads
```

Detailed Emissions Report

A detailed emissions CSV file in the reports folder summarizes emissions of CO_2, carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), volatile organic compounds (VOCs), particulate matter (PM10 and PM2.5), and carbon dioxide equivalents (CO_2e) by commodity and mode. Values depend on emissions factors for associated vehicle types, whether for the default vehicle in the XML or a user-created vehicle.

Optional Exercise – Vehicle Types

To run this exercise, execute run_v8.bat in reference_scenarios\rs6_commodity_mode\Exercise. The run should take 10-15 minutes.

This optional exercise demonstrates the use of the commodity mode input file to assign custom vehicle types to the road, rail, or water modes.

The input file commodity_mode.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. Note that the custom vehicles functionality currently is *not* compatible with CO_2-based optimization.

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

Figure 15: Scenario 6 Exercise commodity mode data file (commodity_mode.csv).

In comparing reports with the default example, note the differences in truck loads, vehicle-distance traveled, fuel burn, and CO_2 emissions for pet_prods traveling by road. These differences are due to the different truck assignments.

```
RESULTS
 -----------------------------------------------------------------------
 ...
 O2 :  Optimal Objective Value:   24,609
 ...
 P_ :  NETWORK_USED_PIPELINE_CRUDE_TRF_RTS:            577.07 :             mile
 P_ :  NETWORK_USED_PIPELINE_PROD_TRF_RTS:   1,500.04 :          mile
 ...
 P_ :  PET_PRODS_CO2_ROAD:        932,712.21 :          grams
 ...
 P_ :  PET_PRODS_FUEL_BURN_ROAD:            87.24 :    Gallons
 ...
 P_ :  PET_PRODS_VEHICLE-DISTANCE_TRAVELED_ROAD:       1,116.01:             vehicle-mile
 ...
 P_ :  PET_PRODS_VEHICLES_ROAD:   40.00 :    truck_loads
```

Reference Scenario 7 – Capacity and Background Flows

Instructions: to run the Capacity and Background Flows Scenario, execute run_v8.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.

KEY CONCEPTS:

- Link capacities
- Link background flows
- Basemap options

KEY FILE(S) IN FOLDER:

- Alternative network with FAF4 roads *(in common_data/networks folder)*

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:

- `Base_Network_Gdb` is set to the full file path of the FAF4 Capacity version of the FTOT Contiguous U.S. network, instead of the more recent version of the network. The default road network does not support road capacity constraints, and all capacity-constrained scenarios should utilize the FAF4 Capacity version of the FTOT network.
- The `Rail`, `Water`, and `Pipeline` (crude and petroleum 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: 1,318,398
...
P_ :  FREIGHT_BULK_FUEL_BURN_ROAD:          7,088.75 : Gallons
...
P_ :  FREIGHT_BULK_TRANSPORT_COST_ALLMODES:   263,611.66 : usd
...
P_ :  DEST_25005_DESTINATION_DEMAND_OPTIMAL_FREIGHT_PARCEL_ROAD:    10,000.00 : ton
```

Reference Scenario 8 – CO_2-based Optimization

Instructions: to run the CO_2-based Optimization Scenario, execute run_v8.bat in reference_scenarios\rs8_co2_optimization. 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 this scenario is to demonstrate inclusion of the social cost of CO_2 emissions from transport in route optimization of a simple supply chain scenario. This scenario also demonstrates different methods for exploring optimal solution results and the corresponding cost components contributing to the optimal objective value. For more information on FTOT's ability to use the cost of CO_2 emissions in the supply chain optimization, consult Section 4 of the FTOT User Guide.

KEY CONCEPTS:

- CO_2-based optimization
- Costs reporting

KEY FILE(S) IN FOLDER:

- None

Input Data

The input data in this scenario resembles Quick Start 1 (QS1), 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 addition of CO_2 cost to the scenario, this scenario is best compared to a successful run of Quick Start 1, which serves as a baseline version of this reference scenario. This reference scenario will follow a similar route but include additional metrics in the report related to CO_2 emissions costs.

This scenario's inputs are identical to QS1 except for the addition of three elements in the scenario XML file: Transport_Cost_Scalar, CO2_Cost_Scalar, and CO2_Unit_Cost. The values of both scalar parameters are set to 1.0, indicating that the costs that FTOT will optimize on will be the unscaled sum of the weighted transport cost and CO_2 costs associated with transportation. The CO2_Unit_Cost parameter sets the monetary cost of a unit of CO_2 emissions (similar to the modal cost parameters defining the transportation cost per ton-mile) and uses FTOT's default value of 191.0 USD per ton.

```
<CO2_Optimization>
  <!-- The optimization problem accepts a weighted combination of routing
    cost and CO2 emissions cost. Weights between 0.0 and 1.0 can be entered
    below for each cost element. -->
  <!-- The default is to assign full weight (1.0) to routing cost and no
    weight (0) to CO2 emissions cost. -->
 <Transport_Cost_Scalar>1.0</Transport_Cost_Scalar>
 <CO2_Cost_Scalar>1.0</CO2_Cost_Scalar>
  <!-- The following cost is applied to each unit of CO2 emissions. Cost
    should be entered in default currency units per mass unit of CO2. -->
 <CO2_Unit_Cost>191.0 USD/ton</CO2_Unit_Cost>
</CO2_Optimization>
```

Viewing Results

To check your Scenario 8 results, open the generated text report and compare your values to those below. The report contains a few new lines compared to the baseline QS1 scenario: CO2_COST for the scenario and for each commodity, and ROUTING_COST_FROM_TRANSPORT for each commodity.

The CO2_COST lines in the Scenario Summary and Commodity Summary sections are only included for scenarios with a non-zero scalar for CO_2 costs. The values in the report equal the product of the CO_2 emissions and CO_2 unit cost.

The ROUTING_COST includes the scaled cost of CO_2 emissions based on the CO2_Cost_Scalar, CO2_Unit_Cost, and CO_2 emissions from transport of the optimal solution. As a result, routing cost for Scenario 8 is higher than the routing cost in QS1, even though the TRANSPORT_COST in the two scenarios is equal.

The additional report line ROUTING_COST_FROM_TRANSPORT_FRAC provides the portion of the routing cost that comes from the impeded transportation costs. This is reported as a decimal between 0 and 1 (in this scenario, 0.95), indicating that 95% of the routing cost value for the scenario came from transport cost and the impedance weights.

```
RESULTS
----------------------------------------------------------------------
...
O2 : Optimal Objective Value:    2,797
...
P  :  CO2_ALLMODES:   722,858.13 :          grams
P  :  CO2_ROAD:       722,858.13 :          grams
P  :  CO2_COST_ALLMODES:         152.19 :   usd
P  :  CO2_COST_ROAD:             152.19 :   usd
...
P  :  TRANSPORT_COST_ALLMODES:   2,567.97 :           usd
P  :  TRANSPORT_COST_ROAD:       2,567.97 :           usd
...
P  :  BLUEBERRIES_ROUTING_COST_ALLMODES:    2,797.12 :           usd
P  :  BLUEBERRIES_ROUTING_COST_ROAD:       2,797.12 :           usd
P  :  BLUEBERRIES_ROUTING_COST_FROM_TRANSPORT_FRAC_ALLMODES:      0.95 :     fraction
P  :  BLUEBERRIES_ROUTING_COST_FROM_TRANSPORT_FRAC_ROAD:          0.95 :     fraction
...
```

The costs_TIMESTAMP.csv report file and the Costs Breakdown story point in the Tableau workbook present the different cost components that go into the optimization in more detail. Both outputs provide unscaled and scaled values for each type of cost considered by FTOT; more details about how each cost is defined can be found in the Technical Documentation and User Guide. In the Tableau workbook, visuals for both unscaled costs and scaled costs can illustrate the impact of the Transport_Cost_Scalar and CO2_Cost_Scalar in calculating the optimal objective function value and route. In this scenario, since both scalars are set to 1.0, the unscaled and scaled values are identical, with emissions-related costs contributing approximately 5% to the objective function value.

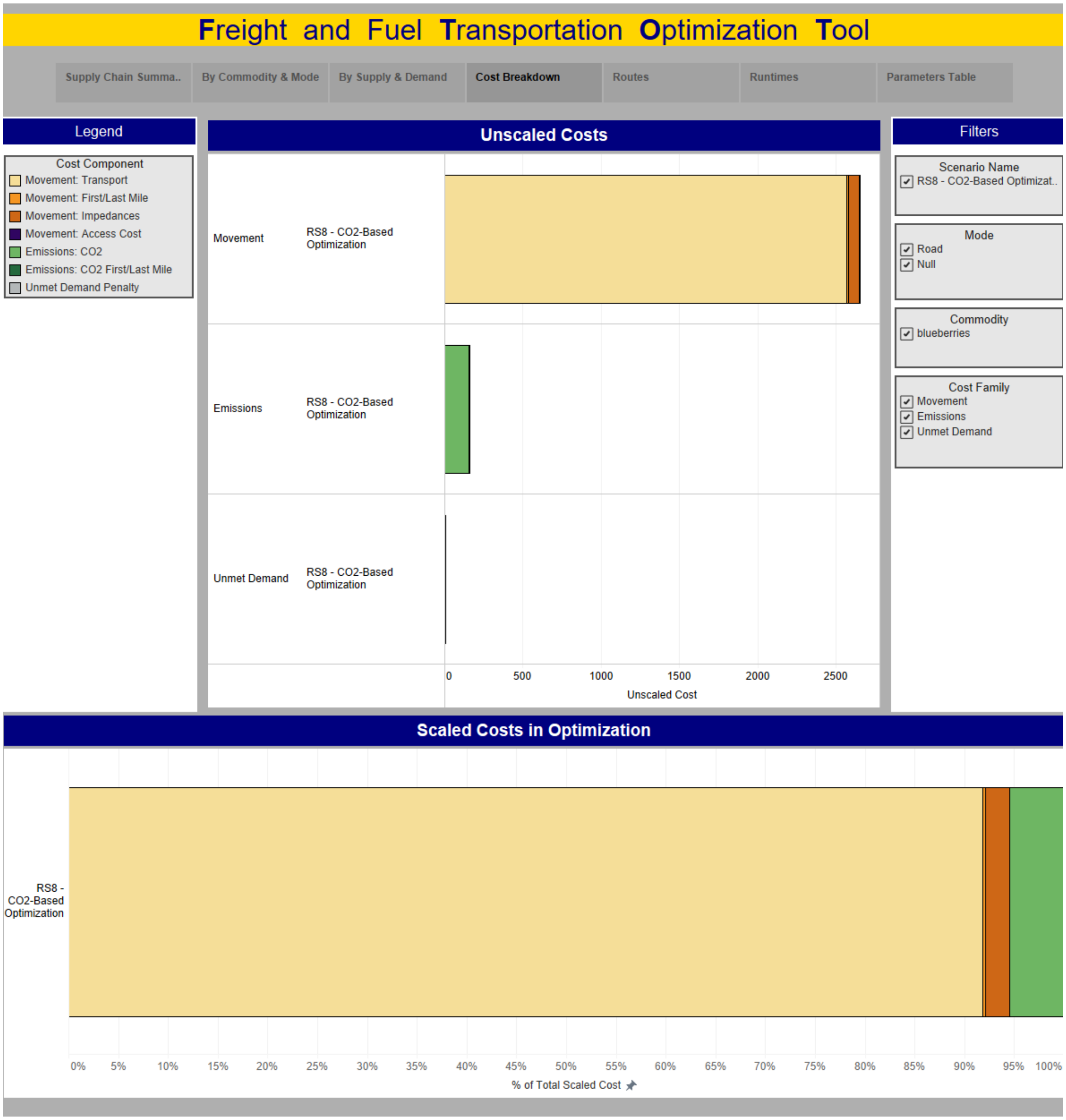


Figure 16: Cost Breakdown story point for Reference Scenario 8.

Users can also compare the maps generated by the run with those in the Map Appendix folder. The maps will show a route identical to the optimal route used in QS1.

Reference Scenario 9 – Scenario Comparison Dashboard

Instructions: to run the Scenario Comparison Dashboard Scenario, execute the run_v8.bat in each of the four subfolders in reference_scenarios\rs9_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. A full description of this scenario is below, including the expected results.

Purpose

The purpose of Scenario 9 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.

KEY CONCEPTS:

- Scenario Compare Tool
- Tableau dashboards
- Network density reduction (NDR)

KEY FILE(S) IN FOLDER:

- run_ftot_tools.bat *(in C:\FTOT folder)*

Input Data

The Scenario 9 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 petroleum 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 by double-clicking run_ftot_tools.bat from the C:\FTOT folder. From the FTOT Tools menu options, run the Scenario Compare Tool. See Sections 6 and 7 of the User Guide for additional information on FTOT Tools and on generating scenario comparison dashboards. Specify C:\FTOT\scenarios\reference_scenarios\rs9_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 (Figure 17) present each scenario's transport cost, vehicle-distance traveled, fuel burn, and CO_2 emissions relative to the scenario from Exercise 1.

Note that network density reduction (NDR) has been enabled for all four exercises in Scenario 9, so additional results on the shortest cost routes between facilities are shown on the Routes dashboard (Figure 18). While the Routes dashboard will always appear, it will only display results for scenarios being compared where NDR is enabled. If NDR is turned off for all scenarios being compared, the Routes dashboard will remain empty.

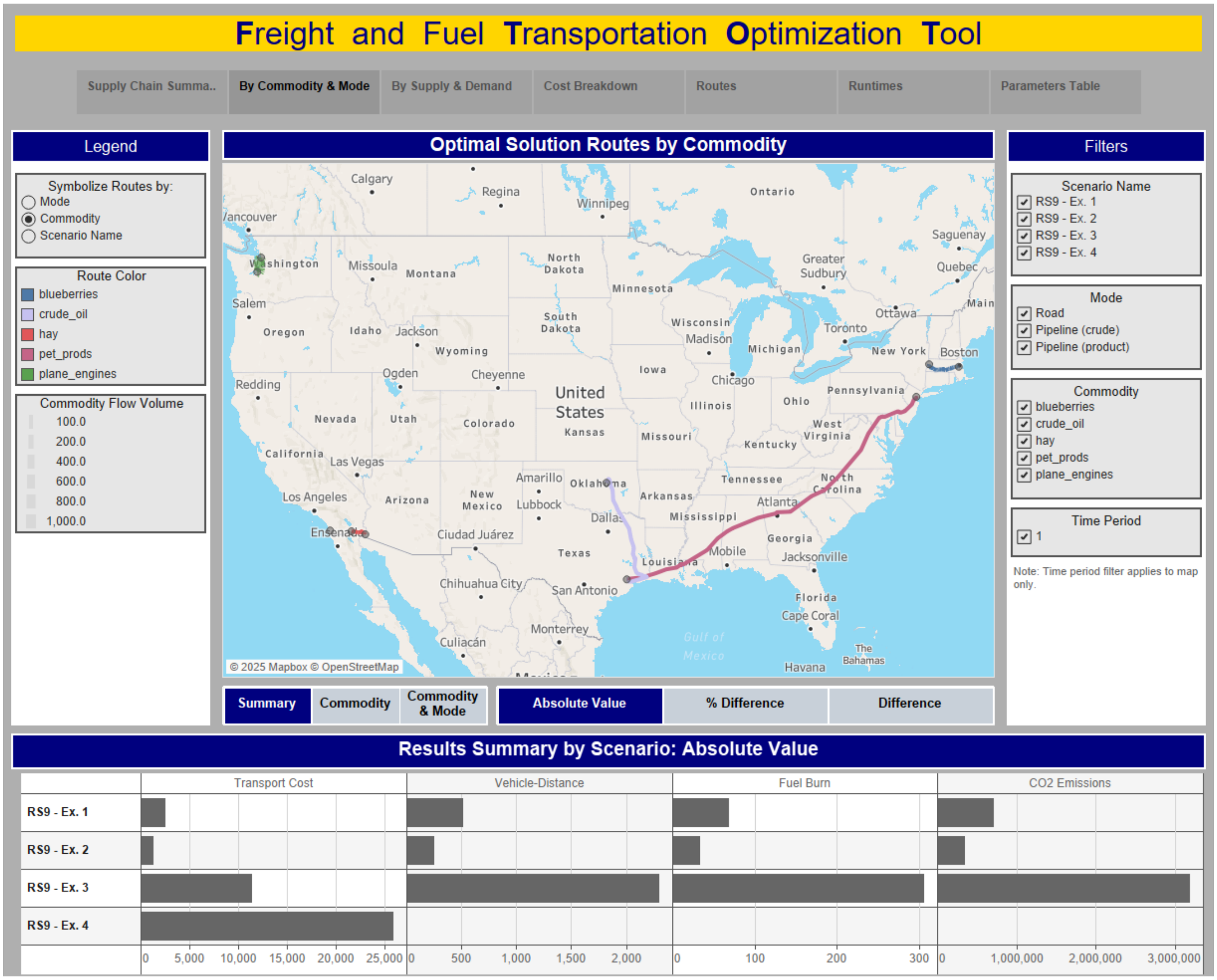
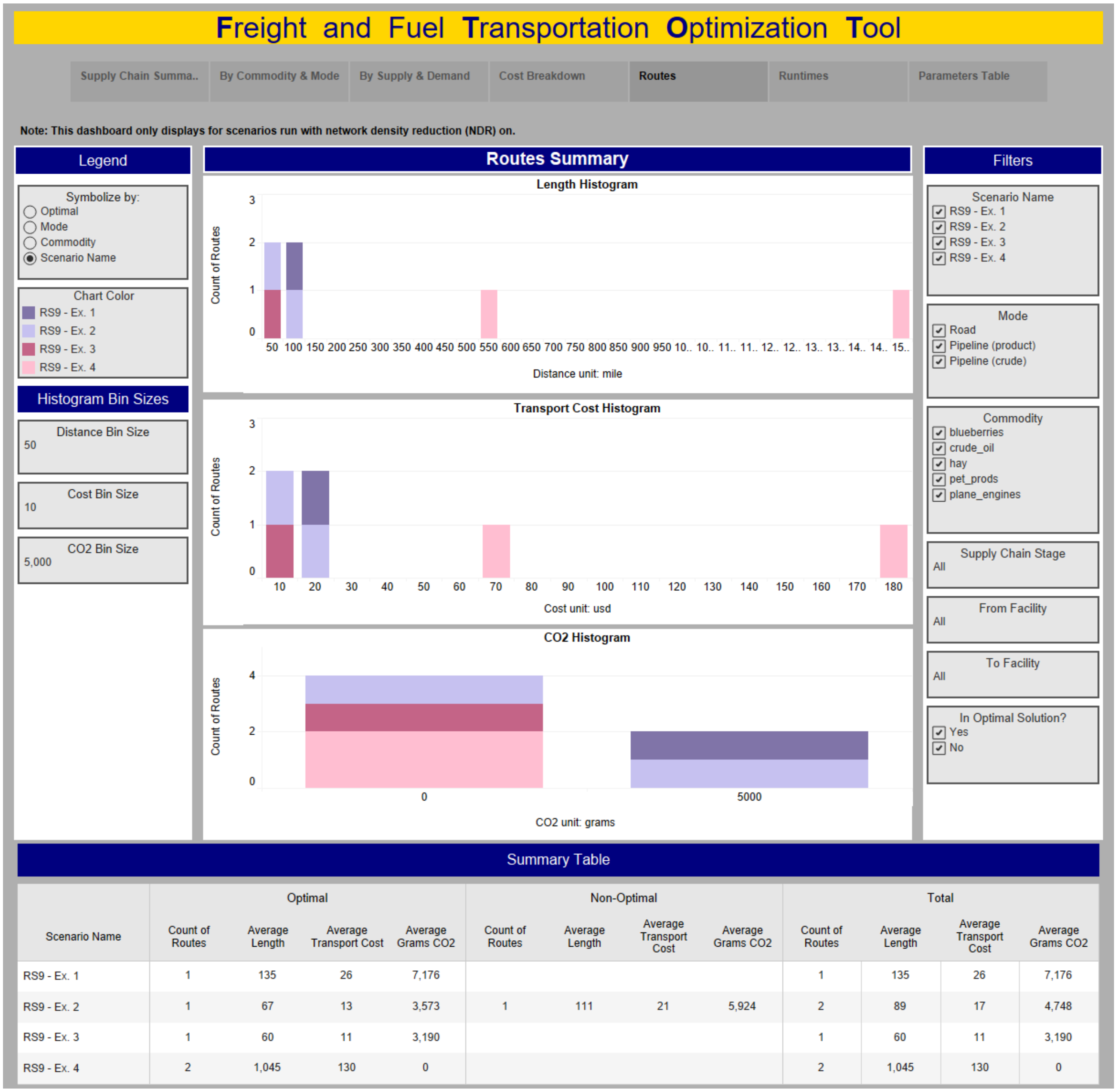


Figure 17: Scenario comparison dashboard showing all four exercises and their absolute difference in scenario results.



Scenario Name	Optimal: Count of Routes	Optimal: Average Length	Optimal: Average Transport Cost	Optimal: Average Grams CO2	Non-Optimal: Count of Routes	Non-Optimal: Average Length	Non-Optimal: Average Transport Cost	Non-Optimal: Average Grams CO2	Total: Count of Routes	Total: Average Length	Total: Average Transport Cost	Total: Average Grams CO2
RS9 - Ex. 1	1	135	26	7,176					1	135	26	7,176
RS9 - Ex. 2	1	67	13	3,573	1	111	21	5,924	2	89	17	4,748
RS9 - Ex. 3	1	60	11	3,190					1	60	11	3,190
RS9 - Ex. 4	2	1,045	130	0					2	1,045	130	0

Figure 18: Scenario comparison dashboard showing routes results for all four exercises.

Acknowledgements

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through FAA contract 693KA9-24-T-00002 under the supervision of Prem Lobo. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.