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Development of the Texas Freight Flow Model (TFFM) Application: A Tool for Assessing Impacts of Changes in Freight Flows on the Texas Highway Freight Network

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16. Abstract

Texas Department of Transportation (TxDOT) Project 0-7037 was initiated to develop a model/tool that could help TxDOT and other transportation planners estimate and assess impacts of changes in freight traffic flow on the Texas Highway Freight Network more quickly than by conducting a full Statewide Analysis Model run. The goal was to produce a tool that could assess proposed change scenarios regarding the introduction of new freight generators or shifting of existing freight facilities/employees to new locations by leveraging the availability of new freight-related economic databases and the use of advanced data analysis methods. Project researchers used several economic databases to determine the estimated number of truck trips for the top 50 industries (by dollars) in Texas and examined statewide county-to-county estimated truck flows based on commodity production and consumption locations. Four analysis modules covering New Firm, Relocate Firm, Warehouse Flow, and Network Closure Scenario impacts were included to advance the model to the minimum viable product (MVP)/Technology Readiness Level 6 stage.

Users of the developed Texas Freight Flow Model (TFFM) enter desired parameters and commodities of interest for analysis within the web-based TFFM app to generate requested scenario outcomes, producing data tables, graphic reports, and charts. The research team also identified several potential advancements that could be implemented to improve the TFFM beyond the MVP in future research. A TFFM user guide is included as Appendix F of this report.

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CHAPTER 1. INTRODUCTION

PROJECT OVERVIEW

Texas Department of Transportation (TxDOT) Project 0-7037: Develop Models for Freight Flows and Commercial Travel Patterns within Texas Urban Regions was initiated to develop a model/tool that could help TxDOT and other transportation planners estimate and assess impacts of changes in freight traffic flow on the Texas Highway Freight Network (THFN) more quickly than by conducting a full Statewide Analysis Model (SAM) run. More specifically, the goal was to use the tool to assess proposed change scenarios regarding the introduction of new freight generators or shifting of existing freight facilities/employees to new locations by leveraging the availability of new freight-related economic databases and the use of advanced data analysis methods.

Project researchers used new big data economic and transportation datasets that have been emerging over the past decade to create a web-based analysis tool/web application (app)—called the Texas Freight Flow Model (TFFM)—that uses estimated truck trips for freight movements of the top 50 industries (by dollars) in Texas as a method to generate quicker answers regarding impacts of changes in freight production and consumption. The number of truck trips for each commodity were estimated by converting estimated dollars to tons and then from tons to estimated number of truck trips. To approximate the impacts of these movements, researchers projected county-to-county truck flows based on production and consumption locations. Four analysis modules within the produced TFFM app covering the following scenario impacts were developed:

- **New Firm:** Addition of a new firm with estimated volume of tons/trucks annually in any given county.
- **Relocate Firm:** Movement/relocation of an existing firm or a percentage of its production from one county to another within the state.
- **Warehouse Flow:** Commodity production and consumption locations remaining constant but one or more intermediate warehousing/distribution facilities being added in counties.
- **Network Closure:** Impact of the closure of single or multiple roadway segments of the THFN (in one or both directions) on flow of a specified commodity across the broader regional or statewide network.

Each of these four scenario evaluation tools within the TFFM app were completed to advance the overall model/app to the minimum viable product (MVP) stage/Technology Readiness Level (TRL) 6 as scoped in the original project workplan. TRL 6 technologies are defined by the federal government as “prototype” level models or demonstrations that are validated or tested within a relevant environment but that still require further testing to be fully implemented in an operational environment (*1*).

PROJECT STEPS

An incremental, multi-phased approach was used to improve estimation of freight needs on the THFN and within Texas urban areas over a planned three-year, developmental research period. The research plan called for progressively detailed tasks and software coding efforts meant to achieve the goal of producing a new predictive model/tool that could be used by TxDOT freight planners to anticipate the impacts of a variety of freight developments on flows on the THFN. A stepwise approach was selected for three primary reasons:

- To provide additional room for flexibility in carrying out the research goals.
- To be able to work more responsively with TxDOT and other freight transportation planning stakeholders at the local/regional level throughout development.
- To make better choices on how to proceed with model development based upon the results of prior tasks as they were completed.

Research phases for the project included the following:

- Targeted Literature Review and Data Availability Analysis Phase.
- Model Development Phase.
- Model Integration Phase.
- Model Testing and Improvement Phase.

Ultimately, TxDOT Project 0-7037 was completed over a period of approximately four years. As a foundational step, in years one and two, the project team conducted a targeted literature review focused on identifying the existing or new freight-related data sources/databases and freight tracking methodologies that might be used to advance an efficient and near-real-time model for assessing freight movements systematically. Initial efforts included:

- Reviews of ongoing advances in understanding and managing freight movement (e.g., improved methods in supply chain logistics, new last-mile delivery methods, automated trucks and delivery vehicles, efficiencies developed using big data and machine learning, dynamic/changing trade patterns, and national demographic trends and other factors).
- Identification and documentation of technologies for tracking freight movements (e.g., tracking of general freight routes, tracking and classification of individual freight loads, tracking of individual items, etc.).
- Assessment of available economic data, databases, data tools, and potential mapping technologies that could be applied as sources for the planned model to be developed later in the project.
- Examination of existing freight modeling/planning practices by major metropolitan planning organizations (MPOs) within Texas.

The remaining two years of the project were dedicated to developing the concept model and applying methods to create the interactive TFFM app. The entire process took place with the research team working in conjunction with and following the input of the TxDOT project oversight panel. The TxDOT oversight panel included staff from both the Transportation Planning and Programming Division's Freight Systems Branch and Statewide Modeling Branch. Periodic updates on research progress were also given at TxDOT's annual Research Management Committee 2 meetings throughout the course of the work.

Identification of Early Challenges

The challenges identified early in the project included determining necessary data for achieving the project goals and assessing the upfront costs of required data acquisition, evaluating the trade-offs of using features from differing types of past freight models based on the literature review, establishing a methodology for integration of the model/tool with other existing urban model applications, and identifying required staffing/domain expertise needs for the model building phase to be completed during the last remaining phases of the project. As described in the original project proposal, contemporaneous efforts to achieve related freight modeling work at urban regions throughout the United States had proven to be very expensive and to take multiple years to complete. To address these challenges, a multidisciplinary research team of both freight planning and transportation modeling experts from across the Texas A&M Transportation Institute (TTI) was formed. Undertaking this work to produce a set of freight movement analysis tools at a statewide level was anticipated to be a difficult task in the originally proposed timeline, and ultimately, development of the TFFM app took approximately one year longer than initially anticipated but stayed within the originally proposed budget.

Minimum Viable Product Concept

From the outset of this research, the TTI team worked with the oversight panel to ensure that the ultimate product from the research would be a new and faster freight modeling tool. The concept was to produce the model initially as an MVP that could then be further improved and evaluated to increase its applicability statewide and regionally. This was outlined in the original project proposal from the TTI research team.

The concept of developing an MVP as a first step is widely used in software development but had relevance in the creation of the freight flow model in this project as well. Typically, the MVP terminology applies to an initial app where the result is fully functional but is later incrementally improved based upon the interaction and testing by users in the post-development period. For this project, the initial TFFM app product is one that provides the minimum initial capabilities for sponsors to observe and evaluate results and to provide additional feedback, which, in turn, helps generate further improvements to the model as it is more fully implemented into practice or incorporated into future freight analysis and planning tools for TxDOT. Ultimately, this is the value proposition in developing this app as an MVP rather than as a stand-alone or completed model solution. It has the flexibility built into its structure from the beginning to be updated with additional features while being used and based on user feedback.

PROJECT OUTCOMES

The research performed in this project resulted in the creation of the TFFM. Users of the TFFM enter desired parameters and specific commodities of interest for analysis within the TFFM app to generate desired scenario outcomes in the form of data tables, graphic reports, and charts showing estimated changes in freight flows for a given action. A user guide for the TFFM app is included as Appendix F to this final report. The research team also identified several potential advancements that could be implemented to improve the TFFM beyond the MVP stage achieved within the workplan for 0-7037; these advancements are discussed in Chapter 4 of this report.

ORGANIZATION OF THE REPORT

As stated previously, the goal of the project was to develop a model/tool that would enable faster analysis of changes in freight flows on the THFN. The primary product of the research is the TFFM app. The remainder of this report describes the research efforts over the course of the project in the following manner:

- Chapter 2 details the literature review and other preparatory steps undertaken during the initial two years of the project.
- Chapter 3 provides a summarized overview of the TFFM app development and data integration tasks, which are then more fully described in the listed appendices.
- Chapter 4 describes next steps in development of the TFFM that would be needed to move it beyond the MVP stage/TRL 6 by adding additional features and improvements to the model interface.

Finally, several appendices provide more detailed background information, analysis methods during the course of the projects, and research interim findings. The appendices include:

- Appendix A: Overview of Existing Freight Models.
- Appendix B: Data Tracking and Tracing Technologies.
- Appendix C: Innovative Freight Tracking and Tracing Technologies.
- Appendix D: Data Processing Technologies.
- Appendix E: Texas MPO Freight Planning Activities Literature Review.
- Appendix F: Texas Freight Flow Model (TFFM) User Guide.

Appendix F is written as a comprehensive, stand-alone user guide. It describes in detail how the current TFFM app can be used to produce a variety of maps, reports, and graphs for analyzing and describing the results of freight movement scenarios. These outputs are an initial step in helping freight planners more quickly answer questions and examine impacts.

CHAPTER 2. TARGETED LITERATURE REVIEW AND MODEL DEVELOPMENT PLANNING

OVERVIEW

Task 2 of Project 0-7037 called for a review and assessment of the state of the practice for freight modeling and related freight movement technologies. The research team reviewed ongoing technological advances in understanding and managing freight movement and current and recently completed modeling efforts throughout North America for methodologies that might be applicable to improve existing urban freight models in Texas. In addition to the work planned in these two areas, TxDOT review panel members asked that the research team add an investigation of MPOs in the state to assess the current state of the practice in freight modeling at the MPO level during one of the early panel meetings.

TARGETED LITERATURE REVIEW

Detailed findings from the targeted literature review are included in the appendices of this report as noted. The investigated topics were:

- Existing types of freight models (Appendix A).
- Data tracking and tracing technologies (Appendix B).
- Innovative freight tracking and tracing technologies (Appendix C).
- Data processing technologies (Appendix D).
- Texas MPO freight planning activities (Appendix E).

SUMMARY OF FREIGHT MODEL TYPE REVIEW

As covered in more detail in Appendix A, based on the review of the prominent freight modeling methodologies, there is no one solution for freight modeling, and there usually exists a trade-off when it comes to model characteristics such as adaptability, integration, data needs, etc. Table 1 summarizes the potential value/trade-off associated with each of the discussed models in terms of data needs, data costs, and model complexity. Additionally, every model has at least one trade-off or shortcoming, making the process of selection of a model highly subjective. For instance, while disaggregate mode share models are highly sensitive and ideal for scenario planning, they are costly, data intensive, and low on adaptability. Similarly, aggregate mode share models rate low on cost and data needs and are highly adaptable but are not an ideal choice if the stakeholders are looking for a model appropriate for scenario planning.

Table 1. Freight Model Type Comparison.

Freight Model Types	Aggregate (A) or Network (N)	Complexity*	Data Needs*	Adaptability*	Scenarios*	Integration*	Maintenance/ Data Costs*
Commodity-Based Input/Output (IO) Models	N	H	H	M	M	M	H++
Control Total and Trip Table Factoring**	N	H	M	M	L	M	M
Aggregate Mode Share Models	A	M	M	H	L	L	L
Disaggregate Mode Share Models	N	H++	H++	L	H	H	H++
Time Series Models	A/N	L	L	L	None	L	L
Data Driven**	N	M	M	L	M	M	M
Graph Network**	A/N	M	M	M	M	L	M

*L=Low, M=Medium, H=High, H++=Very High.
**Models not included in SHRP2.

The identified gaps revealed the need for additional analysis tools to supplement the current Texas SAM. In particular, the need for an analysis toolkit that could be used to analyze urban commercial freight activities as well as tie freight activities at concentrated trade areas such as ports or industrial areas to higher-level geographies of commodity flow was indicated. Initial thought was that the latter could be undertaken using the graph-based models, which could be developed incrementally using existing commodity flow data and be further augmented with supplemental data sources such as network and sub-area node characteristics. Further, the urban commercial freight impacts could be investigated using a data-driven modeling framework that could be developed through synthesis of traditional commercial travel data with emerging passive and land use data sources.

SUMMARY OF DATA SOURCE REVIEW

Identified Data Sources and Assessment

A detailed discussion of the identified data sources and their assessment for applicability in Project 0-7037 is included in Appendix B. Among the sources for freight data examined were:

- Private-Sector Data Providers.
  - Transearch.
  - Datamyne.
  - HERE Routing API.
  - Google Maps.

- Business-to-Business (B2B) Data.
- National Performance Management Research Data Set (NPMRDS).
- Regional Integrated Transportation Information System (RITIS).
- Federal Highway Administration (FHWA) Freight Analysis Framework (FAF) and Commodity Flow Survey (CFS).
- Bureau of Transportation Statistics (BTS).
- Port/Border Freight Data.

Data Conclusions

Each source of freight data has both strengths and weaknesses, as discussed in Appendix B. It is important to remember that many of the identified data sources are not the first source of data, but derivatives of primary data may provide the most comprehensive collection of freight datasets. For instance, the NPMRDS relies on the American Transportation Research Institute (ATRI) for freight data. RITIS retrieves data from third-party providers such as HERE, INRIX, and TomTom. The FAF uses the CFS and international trade data as the main components of data sourcing. The BTS freight information includes the intermodal transportation and national transportation databases and statistics from the nation's transportation systems. One of the handicaps of these data sources is that some of the provided information may not be regular and consistently available.

SUMMARY OF INNOVATIVE SOURCES AND USES OF FREIGHT DATA REVIEW

Appendix C includes the analysis of new or innovative sources and uses of freight data at the time this review was conducted in 2021. Most of the sources identified in the above section provide limited information in some data elements; for instance, one of the most important constraints of existing data sources is the limited ability to provide information in useful terms of the commodity goods/freight being handled. This limitation is many times due to the nature of the data collection technology that is used, where the objective is vehicle volume estimation rather than a direct measure of goods moved by weight or units. The lack of data on commodities (goods) handled often prevents freight modeling from providing visibility on the impacts of truck movements on supply chain performance and ultimately on competitiveness and the overall economy. This is also one of the primary drivers for public investment decisions. To help overcome this lack of information, this section describes the steps taken to examine potential new sources and uses of freight data to address this issue. Table 2 shows the results, discussed more fully in Appendix C, in three distinct areas—data collection, data transmission, and data processing.

One of the most important aspects in freight modeling is data consolidation. The need for consolidation arises because no single source can currently provide sufficient data for a comprehensive freight analysis. In fact, even when consolidating several of the identified data sources, some assumptions would need to be made in order to estimate some variables of an eventual model. This issue is important because the effort to consolidate information from several sources (some of them new) implies data standardization, system communications, and coordination. The latter represents a major challenge in model development and its application.

Table 2. Technologies and Data Elements.

Technology	Data Elements			
	Time	**Distance/OD**	**Volume**	**Cost**
Data Collection				
Radio Frequency Identification (RFID)	✓	✓	✓	
Optical Codes	✓	✓	✓	
Inductive Technologies	✓	✓	✓	
Weigh-in-Motion (WIM) Systems	✓	✓	✓	
Video Vehicle Detection	✓	✓		
Wireless Sensor Network (WSN)	✓	✓	✓	
Biometrics	✓	✓	✓	
Data Transmission				
RFID	✓	✓	✓	
Bluetooth	✓	✓	✓	
Global Positioning System (GPS)	✓	✓	✓	
WSN	✓	✓	✓	
Real-Time Location System (RTLS)	✓	✓	✓	
Machine-to-Machine (M2M)	✓	✓	✓	✓
General Packet Radio Service (GPRS)	✓	✓	✓	
Global System for Mobile (GSM)	✓	✓	✓	
4G Long-Term Evolution (LTE)	✓	✓	✓	
Microwaves	✓	✓	✓	
Data Processing				
Advance Planning and Scheduling (APS)	✓	✓	✓	✓
Enterprise Resource Planning (ERP)	✓	✓	✓	✓
Warehouse Management System (WMS)	✓	✓	✓	✓
Transport Management System (TMS)	✓	✓	✓	✓
Collaborative Transport Management (CTM)	✓	✓	✓	✓

In terms of technologies, the most important aspects are related to their ability to collect, transmit, process, and ultimately provide relevant data with the appropriate attributes. In this way, technologies enable data sources to acquire and provide data. Therefore, the quality of data provided by the different sources is largely determined by the technologies they use. An additional consideration is that there is not a single technology that can provide a comprehensive dataset for freight modeling; therefore, a combination of technologies and sources, which implies data integration, merging, or fusion, may be the best approach for a sound dataset.

Although electronic logging devices (ELDs) are included in the discussion of data collection technologies in Appendix C due to their strong relation with this type of task, they are actually devices based on specific technologies. Data from ELDs help shed light on specific truck activities but would need to be complemented with additional datasets for a more comprehensive freight model and analysis depending on the focus and interests.

Table 3 shows the matrix that relates data sources to measures and basic data elements. Under the "Available" column, the currently available sources are listed. These readily available data sources could be used immediately for analysis purposes. However, they may not be sufficient for the depth and scope of some modeling cases. The pertinence of new data sources to each data element is depicted under the "Proposed" column. In some cases, there is more than one source for a single element, meaning that even though all of them are pertinent, a single one of them may not be sufficient in terms of data completeness, information continuity, or updating. More specifically, even though the economic census provides information related to business establishments, additional input from a supply-chain-oriented economic census or surveys would be needed to complete volume or value of goods per commodity group–business type combination (*2*). This information could also be extracted from and complemented by tax data because value is related to tax and volume. Such additional census data could also provide information on shipment lead time, shipment transportation speed, and shipment origin-destination (OD), all by commodity group. The CFS and FAF, on the other hand, could provide information on the number of miles that goods are being transported and the overall value, complementing other shipment transportation speed and OD data (Table 3). B2B transactional information could be useful to inform metrics such as goods miles traveled (GMT), tonnage, value-miles, and transportation costs. Also, the specific provider of these data sources is identified in the "Data Provider (Name)" column of Table 3.

Table 3. Data Elements—Source Matrix.

Basic Data Element	Measure/Metric	Available	Proposed	Data Provider (Name)
Volume/Value of Commodities	Number of businesses	Economic Census		State Data Centers Establishment Data
	Type of business	Economic Census		
	Volume of goods handled/traded	Not Identified	Additional Census/Tax Data/B2B Data	Datamyne
	Value of goods handled/traded			Datamyne
	GMT	CFS/FAF/B2B Data		FAF/Quetica, Datamyne
	Ton-miles			
	Value-miles			
Travel Time/ Travel Time Reliability/OD	Shipment lead time	B2B Data	Additional Census/B2B Data	HERE, INRIX
Cost	Transportation Cost			Quetica
Travel Time/ Travel Time Reliability/OD	Shipments Transportation Speed	FAF (Estimated)/B2B Data	FAF/B2B Data	FAF/HERE, INRIX

SUMMARY OF NEW AND INNOVATIVE DATA SOURCE REVIEW

This review element covered existing and new data sources and technologies. The use of freight modeling basic data elements and corresponding metrics as a framework allowed researchers to identify and propose new data sources, such as a supply-chain-oriented economic census that would provide value of goods per commodity group per business. New B2B transactional information, which could be used to complement metrics such as GMT, ton- and value-miles, and costs, may also be a possibility. Note that the proposed data sources were selected based on information gaps identified in previous experiences.

Table 4 summarizes the general available and proposed data sources that were considered for each of the four basic data elements.

Table 4. Available and Proposed Data Sources per Basic Data Element.

Basic Data Element	Available	Proposed
Travel Time/OD	1. Highway monitoring systems (GPS data). 2. B2B information.	1. Highway monitoring systems (GPS data). 2. B2B information.
Travel Time Reliability		
Cost	B2B information	1. Supply-chain-oriented census as part of the economic census. 2. Tax data. 3. B2B information.
Volume of Goods	1. CFS. 2. FAF. 3. Economic census.	1. Supply-chain-oriented census as part of the economic census. 2. Tax data. 3. FAF.

SUMMARY OF MPO FREIGHT PLANNING REVIEW

Appendix E describes the efforts under the project to describe MPO activities related to freight. This analysis was done early in the project during 2021, so some of the findings/statuses may have been superseded by other freight-related activities since that time. The freight challenges that Texas MPOs were experiencing were wide-ranging and diverse in magnitude and complexity. Five MPOs reside along the Texas Gulf Coast. One of these, the Rio Grande Valley MPO, also resides along the Texas-Mexico border, as do two others. Additionally, a large concentration of the Texas MPOs reside along the highly populated Texas Triangle, including MPOs for a couple of the largest urban areas in the United States. In addition, new MPOs were recently added to the state's list and did not exist at the time of the Project 0-7037 review. The following trends/highlights were noted:

- **Increasing truck traffic congestion.** When examining the small and mid-sized MPOs, the research team found that most are experiencing freight traffic issues resulting from trucks traveling through the region. Some, such as Waco and Amarillo, have major interstates passing through their region. Others, such as Bryan/College Station, are participating in the development or expansion of major roadways through the region. For example, the Bryan/College Station MPO (BCSMPO) is part of studies related to the east-west I-14 corridor and a north-south concept to move freight via SH 6 and SH 36A from the Texas Gulf Coast to Dallas–Fort Worth while largely bypassing the Houston region to the west.
- **Through-freight movements on secondary highways.** Through-freight movements of the MPOs are not exclusively focused on the major roadways through the MPO regions since many of these movements are occurring on the smaller interstate and state highways in order to bypass congestion and delay on the major urban core roadways. For

example, in Waco, in addition to the I-35 traffic, the MPO is experiencing truck movements northwest along SH 6 toward Abilene and northeast along SH 31 toward Tyler/Longview. Of particular concern are the windmill component movements through Waco toward Abilene. Increased truck movements along state highways often cause increased truck traffic through the middle of smaller rural Texas town centers.

- **Traffic around industrial parks and freight facilities.** Freight activity can also be centered on local economic development activity areas, such as industrial parks or facilities. The parks or facilities are often major employment centers for their MPO regions and require a focus on developing a transportation network that supports higher truck levels and will support continued economic development growth in the future.
- **Impact of rail and other non-highway modal facilities.** Freight in Texas is transported by all the modes of transportation. Access to rail service enhances the economic development opportunities in Texas communities but also introduces safety and mobility concerns. Rail yards and hubs can be significant generators of both larger project loads and truck traffic.
- **MPO staffing and tools.** Staffing is another main consideration for Texas MPOs, especially the small and mid-sized agencies, in that they often have only a small staff to address their freight and other planning activities. This is particularly true in terms of the technical abilities to run complicated computer programming and modeling efforts. Small and mid-sized MPOs stated that they could benefit from easy-to-use and easy-to-learn planning tools. Several MPOs mentioned utilizing the TTI-developed mobility analysis tools, such as the Congestion Management Process Assessment Tool (COMPAT). The larger MPOs are utilizing highly complex travel demand models (TDMs) and freight modeling programs to analyze their region's freight activity. The TDMs in small and mid-sized MPOs may not currently address trucks specifically, although several agencies mentioned efforts to advance these models soon to accommodate truck-specific analyses.
- **Lack of updated freight movement data.** MPOs are using data from the Texas SAM as inputs into their planning tools. This is helpful, but MPO representatives seemed very concerned overall about the lack of other data and/or quality of the available data for their models. External surveys of freight traffic are often not updated on a regular basis since they are performed cyclically around the state. For example, El Paso MPO mentioned that its last external survey (as of the time this review was conducted) was performed in the mid-1990s.
- **Lack of regulatory/enforcement powers.** It is important to recognize that MPOs do not have regulatory control. Enforcement is not an MPO function. These capabilities reside within the member entities, such as cities and counties. These member entities can implement regulations such as truck ordinances. Therefore, a freight challenge or issue cannot be addressed directly by the MPO but requires MPO member agency collaboration and regulatory development/enforcement.

UPDATED MILESTONES AND PROJECT PERSONNEL NEEDS ASSESSMENT

At the completion of Task 2, the research team developed a technical memo that outlined an updated Project 0-7037 deliverables/milestones schedule and evaluated staffing needs to enter the next step of model development. The conclusions presented in that memo were implemented based upon panel input/discussions, and the work proceeded into design and implementation of the TFFM model and app.

CHAPTER 3. SUMMARY OF MODEL DEVELOPMENT AND DATA INTEGRATION TASKS

SUMMARY OF TFFM APP DEVELOPMENT

The TFFM app was developed using Streamlit open-source software. It is hosted on a cloud server, allowing for long-term multiple-user access. Figure 1 shows how the app is integrated to combine several individual modules via a command line interface. That interface was completed as part of the backend application development (presented in more detail in a previous technical memorandum for 0-7037). Each module not only processes upstream data but also serves as a stage to analyze a specific type of interest scenario impacting freight flow, such as the introduction of a new firm (Economic Module), relocation of an existing firm (Geographic IO Module), evaluation of the influence of a new warehousing/distribution location on the highway network (Flow Module), and potential changes or outages in the available highway network (Network Module). Note that the Highway Shipment Module has no associated scenarios, and its primary function is to transform estimated tonnage flows calculated by the model's backend calculations into annual and daily truck equivalents through a sequence of transport mode choice models and a tons-to-truck equivalent conversion procedure. It is also important to note that these modules created during the development of the model led to later development of the New Firm, Relocate Firm, Warehouse Flow, and Network Closure functions of the app described elsewhere in this report and in the TFFM User Guide in Appendix F.

The TFFM app was initially tested on local computers of the research team by accessing the backend modules and from intermediate outputs and external data sources hosted on an Amazon Web Services cloud server over a period of months to identify and correct calculation functions.

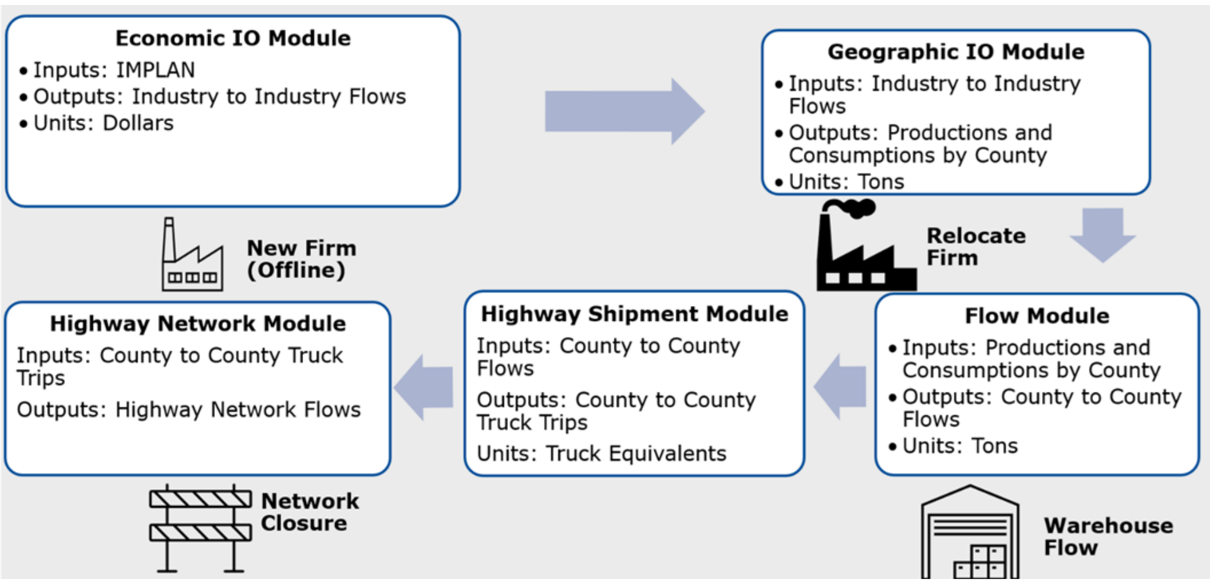

Figure 1. TFFM App Modules and Scenarios.

The research team then transitioned the app functionality from local computers to a web-based version that was tested by the researchers. A user can access the app to either view existing/saved scenario runs for modification with new parameters or generate an entirely new scenario by accessing the specific desired module. Functionality and inputs for each of the modules are discussed in detail in the TFFM user manual included as Appendix F.

MODEL STRUCTURE AND DEVELOPMENT

The final two years of the project primarily involved detailed programming and testing associated with app development. Development steps included the following:

- Integration of backend applications in command line formats (CLI) to the front-end app running on Streamlit and testing by the research team.
- Implementation of scripts to include user interactive data calls in Streamlit to analyze a specific scenario through each module.
- Development of a database to manage scenarios and streamline outputs in the form of tickets to track each analyst's input scenario parameters and specific outputs along with their description.
- Development of capabilities to produce downloadable reports in .csv file format per module with visualization and graphs as well. The .csv file format output allows analysts/users of the app to create their own visualization or do further analysis with the output files.
- Assessment of an open-source tool (AequilibraE) to assign the truck trip table from previous modules onto the THFN and integration of this function into the backend app with the rest of the modules.

To approximate the impacts of changes in statewide freight commodity movements, researchers projected county-to-county truck flows based on production and consumption locations by industry and commodity type. Four analysis modules within the produced TFFM app covering the following scenario impacts were developed:

- **New Firm:** Addition of a new firm with estimated volume of tons/trucks annually in any given county.
- **Relocate Firm:** Movement/relocation of an existing firm or a percentage of its production from one county to another within the state.
- **Warehouse Flow:** Commodity production and consumption locations remaining constant but one or more intermediate warehousing/distribution facilities being added in counties.
- **Network Closure:** Impact of the closure of a single or multiple roadway segments of the THFN (in one or both directions) on flow of a specified commodity across the broader regional or statewide network.

Each of these four scenario evaluation tools within the TFFM app were completed to advance the overall model/app to the MVP stage/TRL 6 as scoped in the original project workplan. TRL 6 technologies are defined by the federal government as prototype-level models or demonstrations that are validated or tested within a relevant environment but that still require further testing to be fully implemented in an operational environment (*1*).

Detailed info and examples on the function of each module are included in Appendix F, the TFFM User Guide. The following sections describe each of the four modules.

Commodity IO (Economic) Module

In the TFFM app, the Commodity IO (Economic) Module utilizes economic supply chain data from IMPLAN as the primary input. This input is then transformed and distributed in terms of U.S. dollar values across Texas counties and then converted into freight tonnages using multiple other input data sources. The module's output provides tonnage and dollar value for each selected commodity as annual productions and consumptions by Texas county. Table 5 and Figure 2 show the various data sources used as inputs for this module and the data flow procedure, respectively. This module generates annual production and consumption tons by commodity and produces estimates for use in the base, new, and relocate firm scenarios. New firm estimates like base year scenarios are run offline due to the time required for calculations to take place; however, relocate firm functions are run online, and results are produced in minutes within the app.

Table 5. Data Sources for the Commodity IO (Economic) Module.

Data Source	Data Description	Data Input
IMPLAN Economic Output	Make and use values by industry for Texas	Total value ($) by commodity produced and consumed by the state
National Establishment Time Series	Time series disaggregated establishment data	Employment
County Business Patterns	Economic data by industries by county	Employment
Quarterly Census of Employment and Wages	Employment and wages reported by employers covering more than 95 percent of U.S. jobs, available at the county, MSA, state, and national levels by industry	Employment
CFS Public Use Microdata Sample Data	Shipment values and weight by Standard Classification of Transported Goods (SCTG) commodity codes	Value ($) for each pound of commodity

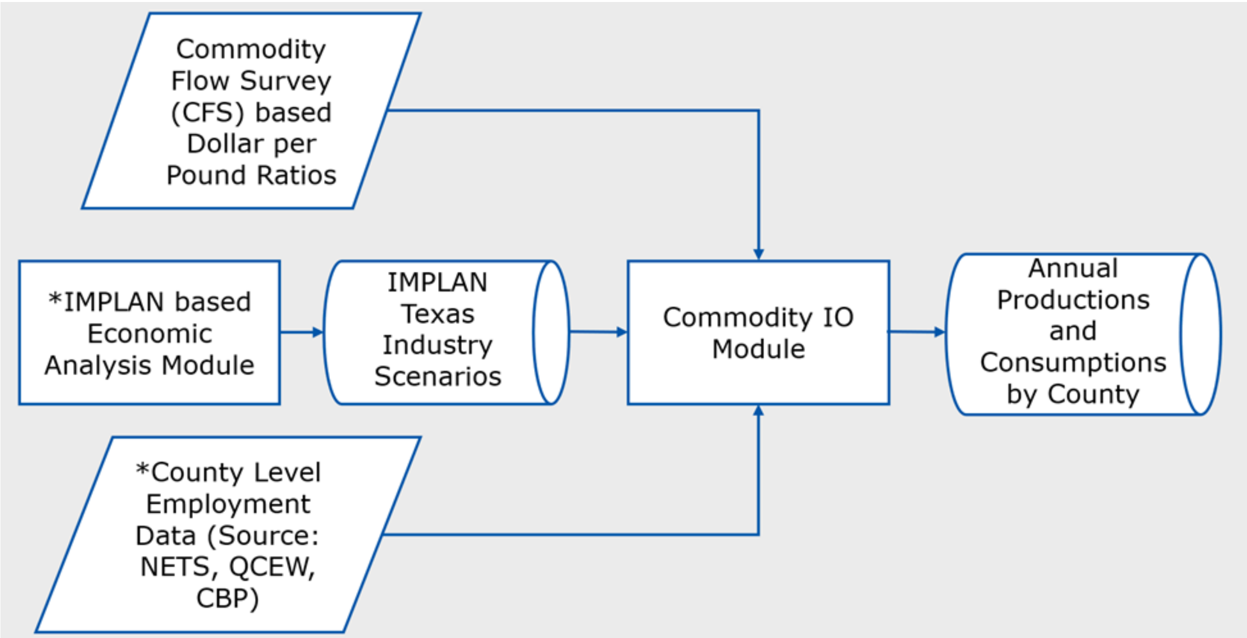

Figure 2. Commodity IO (Economic) Module Data Flow Diagram.

These data input options include:

- **Selection of Employment Data:** The choice of employment data for each commodity is determined by considering the availability and noise level (provided in U.S. Customs and Border Protection [CBP] data). By utilizing three different employment sources, the gaps are effectively filled, and subsequently, the most suitable employment source is chosen for each specific commodity.
- **Distribution of Make and Use Data:** Based on the employment distribution by county for each commodity, the production and consumption totals are distributed among the counties.
- **U.S. Dollar ($) to Pounds (lb) Conversion:** Once the production and consumption data have been allocated to all the counties in the state, the U.S. dollar values are then converted to pounds using the reference CFS shipment value and commodity tonnage. These tonnage values play a crucial role in further converting the data into truck units and gaining insights into implications for transportation infrastructure.

Flow Module

The Flow Module of the TFFM produces annual commodity flow in tonnage for each IMPLAN industry based on the outputs from the Commodity IO (Economic) Module. Figure 3 shows the inputs and outputs of the Flow Module. By default, it produces OD flows by taking input from the previous model on annual productions and consumptions by county and generalized cost matrix. The generalized cost matrix input at this time is a distance-based impedance measure, which can be updated as needed to be travel time or other impedance measures. This information could also be sourced from another model (such as a Texas SAM skim) or from a big data dataset (travel time matrix from INRIX data for time of interest) as desired or available.

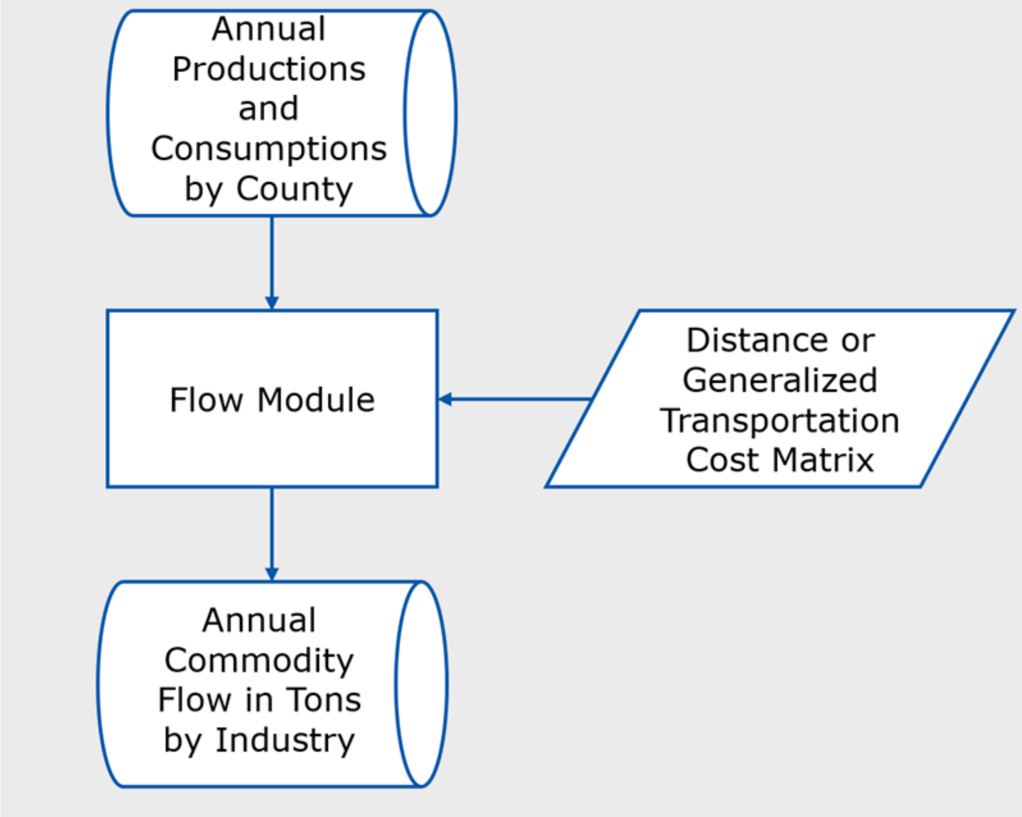

Figure 3. Flow Module Data Flow Diagram.

By default, this module produces tonnage flows for all IMPLAN industries for each year. These flow estimates are produced as direct flows (i.e., without any intermediate points of transfer such as warehouse), referred to as transshipment in this context. Further, this module can produce similar outputs for any upstream scenario, such as development of new firm/resize or relocate from prior modules. This module also includes an alternate scenario analysis option to understand the influence of introducing a transshipment (warehousing) location and is specifically run by commodity (industry).

Transport (Shipment) Module—Estimating Truck Equivalents

Overall, the Transport (Shipment) Module made up of the three functions described in this section yields annual and daily truck trip tables for each examined IMPLAN industry. These truck trips tables can be generated for each base year scenario as well as any scenario that the end user may choose to examine through the front-end application. The current state of the TFFM application has this module integrated with the Commodity IO (Economic) Module and Flow Module. This backend allows users to produce truck trip tables for IMPLAN industries for each base year by default, and for any of the alternate scenarios submitted by the end user in the previous module by specific industry.

The Transport (Shipment) Module of the TFFM app is initiated by reading outputs generated by the Flow Module for base or alternate scenarios. The primary input includes flows between counties in tonnage by IMPLAN industries categorized into 1 of 14 SAM commodity groups. The tonnage estimated to flow between counties for each industry undergoes the following data analysis processing functions, as shown in Figure 4:

- Shipment generation.
- Mode choice estimation.
- Tons-to-truck unit estimation.

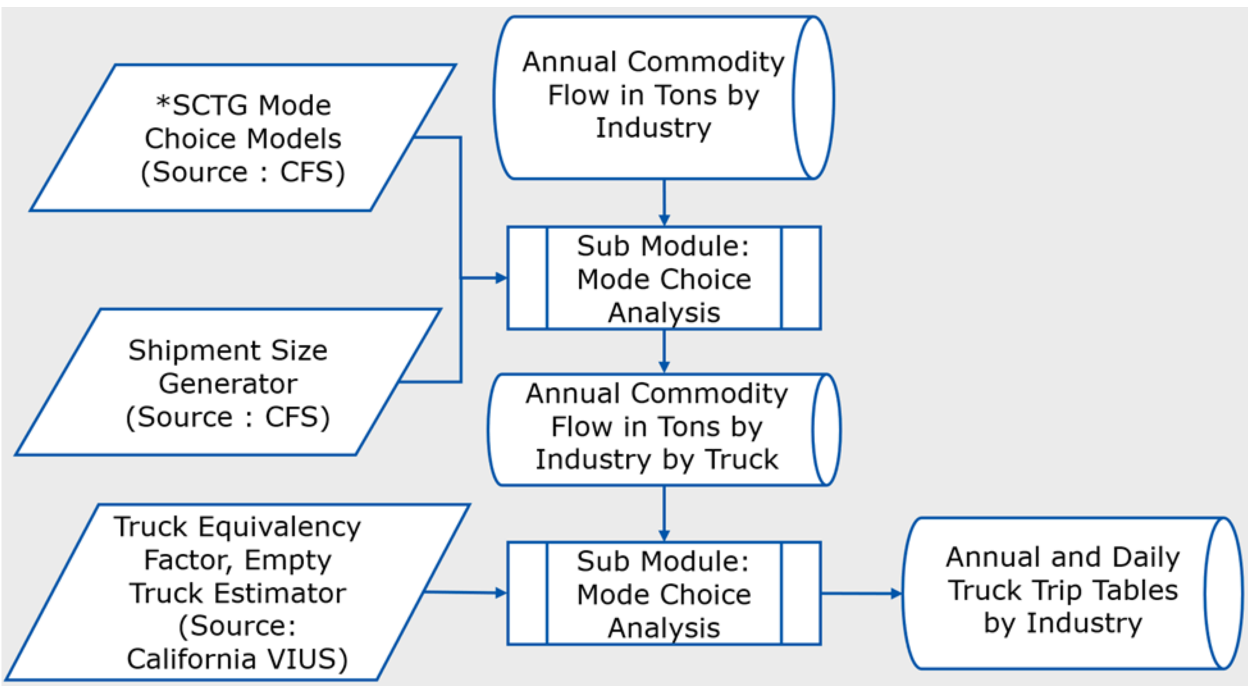

Figure 4. Transport (Shipment) Module Data Flow Diagram.

Shipment Generation

The shipment generation sub-module, the first of the three in this module, distributes the annual tons estimated to flow between a pair of counties into shipments of varying size. This is undertaken for each of the 50 highest ranked by dollar IMPLAN industries for the base scenario. The individual shipments are generated by following the underlying sample distribution of the shipments obtained from the most current (2017) CFS data. To undertake the shipment generation, the annual commodity flows for a given IMPLAN industry are first mapped into a corresponding SCTG category upon which the CFS data are reported. This information is used as a reference to generate the annual individual shipments for each industry's commodities flowing between Texas counties.

Mode Choice Estimation

Next, the mode choice model procedure estimates the mode of transport for each shipment generated from the above function as being either truck or rail. This is achieved by first estimating mode choice models for each SCTG category utilizing the 2017 CFS data. Several logistic (multinomial logit) and random forest machine learning models were developed for each SCTG category, and those yielding the best predictions using CFS test data were subsequently incorporated into the app functionality.

Note that the models were only incorporated into the mode choice estimation function after the data and the models were reviewed by a team of freight experts. Furthermore, each of the models has its own caveat in its data limitations and the restricted ability to map an IMPLAN industry to a more aggregated and restricted SCTG category. For example, not all SAM groups have a mode choice model due to lack of CFS data or small sample sizes, resulting in truck being the default mode. This TFFM app function is designed to be flexible to incorporate model updates and new model structures based on data availability, model fit, and predictive power. Currently, the mode choice function in the TFFM is restricted to classifying shipments as either truck or rail rather than being used to evaluate scenarios, such as assessing changes in shipment size or travel cost.

For those SCTG categories that have mode choice models in place, the shipment mode of transport is primarily predicted based on the travel distance and size of the shipment. This is intuitive and is evident from literature, and in the future, other factors such as transportation cost and travel time could be explored using additional data sources to improve the underlying model and app functionality. The models currently implemented in this function by the TFFM for each SCTG commodity are generated for each shipment estimated to flow between a pair of counties to predict its corresponding mode of transport as either being truck or rail. Those shipments that are predicted to be transported via truck are reaggregated to arrive at estimates of annual tons flowing between counties through highways/trucks.

Tons-to-Truck Unit Estimation

The annual truck tons estimated to flow between counties from the above discussed procedure for a given IMPLAN industry are then transformed into annual and daily truck units. This is accomplished through a methodology developed for FHWA's FAF4 at a national level (*3*). For Texas, the conversion of annual tons by highway (truck) mode follows a procedure developed using California Vehicle Inventory and Use Survey (VIUS) data, which was requested by TTI from Caltrans with support from TxDOT. This methodology could be updated based on VIUS data going forward once new data are released and made available.

Network Module

Daily truck trip tables resulting from the prior modules are then assigned as trips through the THFN under different scenarios through the Network Module of the TFFM app. This module assigns daily truck trips to the highway network with Texas SAM-based auto trips as background traffic and is allocated through a static assignment procedure. Additional details and development procedures along with the code for this module are documented on GitHub. This module allows users to test the routing impacts on freight flows resulting from roadway closures or eliminations.

CHAPTER 4. NEXT STEPS/TFFM IMPROVEMENT PLAN

MODEL IMPROVEMENT PLAN

Several additional features could be developed to further enhance the functionality of the TFFM beyond the MVP status outlined in the Project 0-7037 workplan. Each of the following sections describes further functional enhancements that could take place as part of an implementation project or in future research projects. The indicated additional features are based upon the lessons learned during the TFFM online app creation.

Incorporation of Interstate Flows

Interstate commodity flows (integrating freight commodity flows from areas beyond Texas) could be incorporated through extending the application of the dollar-to-tons conversion methodology within the Geographic IO Module. This could be done through use of the broader national commodity flow data that are available from the IMPLAN model for each base year.

Adding interstate commodity flows would also trigger the need for additional desirable enhancements, such as:

- The probable purchase of a nationwide employment database for subsequent computations in the backend of the TFFM app.
- The addition of a separate module to estimate mode choice based on commodity type and share of long-haul travel (and likely influence of intermodal/non-truck flows).
- The identification of external stations/locations for flows in/out of Texas from other states as well as through border ports of entry and seaports. (International flows would need additional processing, as described in the next section.)

Incorporating International Commodity Flows

Adding international commodity flows to the current TFFM would require the consideration, combination, and synthesis of multiple additional data sources into the model. Inherent in this is additional risk because international and cross-border data sources may not be as robust, readily available, or reliable as those used in the current TFFM for in-state movements.

Also likely would be the need for the use of waterborne traffic data sources such as the Port Import/Export Reporting Service and Automatic Identification System data regarding ship bills of lading and movements to/from Texas seaports. Such tools typically report commodity arrivals at aggregate levels similar to those available from FHWA used in the current model and could be introduced into the modeling framework to account for commodity and timing of international freight commodity flows to, from, and through Texas to the rest of the United States.

Flow Module Enhancement

Large Shipment Size Modeling

In the current TFFM, annual shipments (in tons) are estimated to flow between a given pair of zones and are converted into individual shipments using distribution models based on prior findings of the CFS. The CFS is produced on a nominal five-year cycle through joint work by BTS, the U.S. Department of Transportation, the U.S. Census Bureau, and the U.S. Department of Commerce. The current TFFM's methodology yields small and moderate shipments of reasonable size (in tons) but does not capture or generate some larger shipments in some commodities. This limitation of the current model calls for further enhancements to explore and implement new extreme value models to arrive at estimates of larger shipments that happen infrequently in special cases.

Mode Choice Models

These models are estimated based upon input from an expert panel in the current TFFM for each shipment utilizing the more aggregate categories available in the CFS and could be enhanced further by using larger and more recent sample sizes as they become available from ongoing research and CFS updates. Doing so could become an ongoing maintenance, enhancement, and monitoring effort to keep the model current. The mode choice models of the current TFFM are primarily utilized in the backend application to estimate the share of shipments moving by truck, and then those figures in tons are subsequently computed to arrive at truck equivalents in the Flow Module.

Incorporating Passive/Probe Data

Existing passive probe data acquired/purchased by TxDOT for strategic planning purposes across the work of several divisions could be used more fully in several ways to improve the accuracy of this application. Prior to incorporation of the probe data, a detailed evaluation and analysis of the probe data and related inherent biases (based on factors such as opt-in truck types, seasonality, etc.) would be required, but some of the possible applications of these data for enhancements of the current TFFM app include:

- Utilization of travel time estimates from passive data between counties as a measure of impedance for arriving at flow estimates in place of the distance-based measure that is currently used in the TFFM Flow Module. This information could potentially be an input to evaluate how changing travel times could possibly affect flows and choice of origins/destinations in transshipment movements.
- Disaggregation of county-to-county flows to smaller sub-county regions through evaluation of sub-regional concentrations of origin and destination observed through analysis of passive truck probe data sources.

- Incorporation of probe-data-based auto trip table information as background auto traffic instead of use of the SAM-estimated auto trip tables for estimating this factor in the TFFM model.

Network Module Enhancement

The current TFFM Network Module provides an understanding of the influence/impact of individual road closures on diversion of truck trips through one or more links across the regional network. This function of the model could be improved in the following ways.

Commodity-Level Impact Assessment

Subsegment truck trips by commodity type attribute (whether IMPLAN or SAM) might be used at the link level to assess the extent to which individual commodity type flows are affected as a result of specific link closures rather than overall freight flows.

Commodity-Specific Assessment

The Network Module currently presents a base year assessment. This function can be enhanced by linking it to previous modules to understand commodity-specific link-level effects resulting from:

- Introduction of new firm or firm relocation scenarios and a comparison of the changes in link-level flows from such scenario changes with respect to the base scenario.
- Introduction of warehouses or transshipment points through the flow scenario to assess the change in link-level commodity flows resulting from diversion of a commodity through the warehouse compared to direct flows built into the TFFM base scenario.

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3 Federal Highway Administration. (2016). Freight Analysis Framework, FAF4 Freight Traffic Assignment, Chapter 3. https://fafdev.ornl.gov/fafweb/data/Final%20Report_FAF4_August_2016_BP.pdf. Accessed July 20, 2022.

APPENDIX A: OVERVIEW OF EXISTING FREIGHT MODELS

INTRODUCTION

This Appendix explains the several types of freight models identified early in the project. Freight models have been developed to analyze freight at different geographic and time resolutions from the perspective of the policy questions stakeholders are interested in assessing. Broadly, these models could be categorized as either comprehensively analyzing the entire freight process or being project-specific models developed to understand freight impact along a specific transport network link or corridor.

The family of models that comprehensively model freight are considered cross-sectional in nature. Most of these models are developed analogous to the traditional four-step household travel demand model and, more recently, are being advanced into the activity-based modeling framework. Alternatively, project-specific models are undertaken to evaluate a specific site or link at the transport level utilizing longitudinal time series data. The comprehensive analysis models can be utilized for studying multiple policy and analysis needs (herein referred to as scenarios) at the regional and link levels but are often resource intensive, whereas the project-specific models, although not resource intensive, are undertaken to study a specific corridor or site and have been generally considered more of a project-level analysis method than a modeling tool.

This review describes the evaluation of seven such distinct freight modeling methods and how each of these models or its components and data sources could be used to complement each other to support practitioners in analyzing scenarios across different sectors within reasonable response times. These model types were considered as both stand-alone analysis tools and/or functions that could enhance the traditional four-step framework, making the model to be developed in Project 0-7037 either more sensitive to policy effects or less resource intensive. Each of these model types is discussed in the context of the sequential four-step comprehensive modeling framework. Each model type evaluation has the following sections:

- Model description.
- Model example.
- Advantages and disadvantages.
- Summary and assessment for use in Project 0-7037.

COMMODITY-BASED INPUT-OUTPUT/FOUR-STEP MODELS

Description

Commodity-based IO models provide insights on the regional production/consumption potential across commodities and the flow between industries across regions for either producing intermediate or final products for consumption. Primarily, these models are implemented over larger geographic units with an annual analysis time frame. Independently, this model type can be used across the public sector to estimate freight traffic by linking economic activity to commodity flows—namely a commodity produced and consumed by a geographic area (*1*). This type of model can be used to analyze regional effects of economic scenarios such as growth or reduction in production/consumption or relocation of resources through assertions in this model. For example, scenarios could involve assessing the effect of growth in select commodities and its resultant effect on secondary commodities or intermediate products.

This model type also forms the basis for implementation of a more comprehensive four-step freight model framework, wherein the effect of economic scenarios on the transportation sector is assessed by utilizing the output from IO models. Specifically, first this model type can help assess the direct impact of changes in economic conditions (e.g., commodity demand/production) on mode choice decisions considering the associated transportation and logistics costs. This is achieved through producing commodity-specific trip distribution tables using commodity flow data, which could then be used as input for the commodity mode split analysis. These commodity flows are generally converted to truck equivalents utilizing standard average payloads values from VIUS (*2*) and are subsequently assigned to a regional transportation network to understand their impacts for different policies and scenarios.

Model Example

The Statewide Analysis Model Version 4 (SAM-V4) freight model produced by the Alliance Transportation Group (*3*) for TxDOT is an ideal example of a four-step model based on a commodity-based IO model. SAM-V4 includes trip generation, trip distribution, mode choice, and traffic assignment. The geographic scale of the analysis is determined based on needs and data availability. For instance, the Texas SAM was developed at the county level because the required data inputs (commodity: Transearch, population and employment) were available at this level. The trip generation step of this model uses annual tons per commodity as the unit of measurement for zonal productions and attractions. Utilizing the above data as marginal totals of production and attractions per zone, the trip distribution stage of the model distributes the tonnage moved between zones using the following gravity model function (*3*):

$$T_{ij} = K_i' * K_j'' * P_i * A_j * exp(-\beta * C_{ij})$$

Where:

T_{ij} = Freight tonnage movement between zone *i* and zone *j*.
K'_i and K''_j = Adjustment factors for zone *i* and zone *j*, respectively.
P_i = Productions in zone *i*.
A_j = Attraction in zone *j*.

C_{ij} = Impedance between zone *i* and zone *j*.
β = Coefficient applied to impedance in the exponential function.

The tonnage estimated for each cell representing the flow between a county OD pair for a commodity is further allocated to a subset of a traffic analysis zone (TAZ) within each county by using production and attraction rates available by TAZ within each county. Further, the mode choice model in SAM allocates the commodity flow to one of the following transportation modes: truck, rail, intermodal rail, water, and air. This model, unlike traditional logit choice models which represent a discrete choice (e.g., truck or rail), reflects the share of commodity flow to be transported between an OD pair using a given mode. Thus, these types of models are often referred to as aggregate choice models because they do not necessarily represent a discrete choice such as an individual decision-maker (e.g., shipper) and/or their mode choice (truck vs. rail) for a specific commodity. Specifically, the aggregate mode choice model allocates shipments between an OD pair to modes based on their direct and indirect costs as a function of multiple explanatory variables. Mode choice is allocated in the SAM freight mode choice model using a utility function within an incremental logit formula shown below:

$$S'_{ijm} = \frac{S_{ijm} * \exp\left(\Delta U_{ijm}\right)}{\sum_{m}^{M} S_{ijm} * \exp\left(\Delta U_{ijm}\right)}$$

Where:

S'_{ijm} = New share of the flows carried by mode *m* between zone *i* and zone *j*.
S_{ijm} = Existing share of the flows carried by mode *m* between zone *i* and zone *j*.
U_{ijm} = Utility from *i* to *j* of mode *m* among all modes *M*.
ΔU_{ijm} = Change in utility for a given mode (*m*) between zone *i* and zone *j*.

The above model utilizes explanatory variables such as travel cost, travel time, and number of intermodal facilities available near freight activity centers, with the modal constant term in the above equation representing shipment size, frequency, load density, etc. The composite measure using the above variables is referred to as the total logistic cost (TLC). As the TLC for a given mode increases, the model shifts the share of commodities flowing between an OD pair to competing modes available. This can be used to understand the effects of different transportation-related scenarios and how they alter share across modes via the introduced variables (travel cost, shipment size and frequency, etc.). The estimated effects could be achieved through calculation of elasticities—direct elasticity and cross elasticity. In the direct elasticity method, change in demand for a mode is estimated with respect to its own price, whereas in the cross-elasticity method, the change in demand for a mode is due to change in the price of competing modes (see Koppelman and Bhat [*4*] for more details). The freight mode choice model in the Texas SAM uses the cross-elasticity method to allocate modes in its IO model.

As is apparent, the aggregate mode choice model does not explicitly capture behavioral characteristics such as those of the decision-maker (e.g., a shipper) and their mode choice decision. The subsequent section of this review discusses some recent developments that tend to represent more behavioral aspects related to the decision-maker and their choices, but the trade-off is the increased data needs and computational complexity that result from those features being added. The final step in SAM following the mode choice model is freight truck assignment, in which the freight tonnage forecasted annually is first converted to daily estimates and then assigned to the transportation network. This task involves three steps: disaggregating county-level flows to the TAZ level, converting annual tonnage to weekday and weekend, and converting tonnage to truck trips by applying payload factors to convert tonnages into truck flows.

Advantages and Disadvantages

Commodity-based four-step models are well suited to analyzing regional freight movements. For example, in terms of economic-transportation linkages for scenario analysis, one could assert scenarios such as potential economic changes in production/consumption level across commodities to evaluate the subsequent impact on long-haul freight movement. It is also feasible to assert the influence of transportation and logistics costs in ascertaining the effect on mode shifts across commodities at the regional level.

This type of model cannot be used to analyze freight activities at finer spatial and temporal resolutions, such as to explicitly understand the effect of potential changes in port operations, trade relations, or relocation of a business. Specifically, the model lacks the ability to understand urban freight movements such as short/local freight delivery trips or drayage movements around ports and to/from distribution centers. Further, it cannot capture empty movements (i.e., those trips that are made after delivery of a commodity), which need to be modeled separately.

Overall, this model seems to be more suitable to analyzing regional freight movements and understanding the economic effects at this scale. Alternatively, one could consider vehicle-based models to understand the impact from empty trips but would have to trade-off behavioral analysis capabilities across regions and modes possible using the commodity-based IO method.

The IO models require an array of data from multiple sources, such as traffic counts, existing and forecasted commodity flow data, employment and population data, characteristics and location of major freight generators, forecasts of economic activity, and technical coefficients, to extrapolate existing production and trade patterns into the future. These data might not all be available for all regions and for the same time frame and at the desired spatial resolution.

Summary

Commodity-based IO models are ideal for regional-level studies due to their aggregate nature. These models link economic relationships between consumers and producers to traffic flow, unlike other freight models. The Texas SAM is an ideal illustration of this type of model, which precludes any need to recreate such models in the state of Texas. However, since commodity-based models are not detailed enough to capture urban travel and are difficult to adjust for policy or economic scenarios, a model that fulfills these needs for Texas is warranted.

TRIP FACTORING METHODS

Description

In the four-step model framework, the trip table seen in the last section is derived using commodity flow data as part of the trip generation and distribution step. This is a significantly resource-intensive exercise involving multiple data sources to arrive at OD trip tables. In contrast, trip factoring methods exclude the above steps, utilizing trip tables directly from an external source.

OD Trip Table Factoring Method

The OD trip table factoring method uses the four-step modeling framework, wherein a base trip table is introduced from an external source such as a commercial vendor, survey of shippers, and/or existing observed freight flows (*5*). Emerging big data sources could also be used as a complement in this context; these sources could provide more recent and timely flow data but may or may not represent all modes and would be like the vehicle-based models discussed in the last section. These base trip tables are then factored using growth rates calculated with economic or employment data to arrive at projected trip table estimates, which are then adjusted using an iterative proportional fitting process. These tables are then subsequently fed into the remaining steps of the four-step process of mode split and network assignment to arrive at network- and link-specific estimates of freight impact.

Trip Flow Factoring Method

In addition to the above approach, factoring methods can also be applied at a specific network link or site level, referred to as the trip flow factoring method. In this method, the inbound and outbound freight trip generation potential is modeled without accounting for any regional characteristics. Thus, the method eliminates the resource required to implement a four-step model framework. It is often used to estimate short-term forecasts that are project specific, such as to understand freight impact from a port or on a specific roadway segment. These models can be used to either estimate future flows through a given facility or potential diversion to a parallel or competing facility. Like the OD trip table projections, the future flows in this method are estimated using secondary socioeconomic data through growth rate calculations, assuming they are constant over time. Future flows could be calculated as a ratio of historical traffic volumes or economic indicators such as gross state product (GSP) by commodity around the area of interest (region, roadway segment, or port):

$$GF_{ij} = \left(\frac{GSP_i}{GSP_j}\right)^{(j-i)}$$

where *GF* is the growth factor calculated using general or commodity-specific GSP across two periods (*i*,*j*). At a network link level, these growth rate estimates calculated using historical data could then be applied to existing/base year traffic volumes to arrive at future year volumes at either a corridor level or a regional scale as follows: $aadt_{proj} = \ aadt_{exist} \ * GF$. More advanced methods that take more than two periods of data (using time series models) to understand freight impacts at this level do exist and are discussed in detail later in this appendix.

Model Examples

State agencies have used factoring methods either as an interim modeling tool or to understand project-specific freight impacts. The Ohio Department of Transportation (ODOT) developed a factored trip table model to estimate freight truck volumes segmented by origin, destination, payload, value, and commodities carried (*5*). This model was produced using OD data from 1998 Transearch data, which reported freight shipments moving into, through, and from Ohio. It was adjusted to Ohio's economic forecast for 2025 using data from economic firm DRI-WEFA's developed model. Further, analogous to the mode choice component in the commodity-based four-step model, the modal splits in this model are estimated based on existing market share and then assigned to each mode's transportation network using fixed paths. One example is the Minnesota Department of Transportation (MnDOT) trip flow factoring method used to analyze future traffic on the US 10 corridor. In this model, the truck volumes for future year were based on the industrial and labor projections for this region. Utilizing the employee projections, the model estimated the truck trip generation rates for the year 2020 using FHWA's quick response freight manual.

Advantages and Disadvantages

One of the major advantages of this method is that it can be developed from minimal data and does not need data from multiple data sources compared to the traditional four-step framework. This makes the model less resource intensive in terms of its computing needs and cost. However, it also loses the ability to capture the effect of economic policies. From a practitioner's perspective, a highly specialized skill set or specific software tools are not needed to implement this method. The link-level trip flow factor models are even more confined in scope and data needs and thus are often suggested as a tool for short-term forecasting. None of the flow methods are capable of capturing national- or state-level policy effects such as those resulting from shifts in economy or trade patterns. However, they function well as a quick response tool for examining local and regional growth-related impacts from freight.

Summary

Overall, trip factoring methods are not a model but, instead, a simple and effective methodology that can be integrated into other models to infer travel characteristics using already available data and resources. These methods can be successfully applied to truck and freight studies but are not done so commonly. Their ease of use and quick turnout make these methods a promising candidate as a potential tool to analyze specific scenarios.

MODE CHOICE MODELS

In the context of the four-step model framework, most of the freight mode choice models implemented to date are aggregate mode share models. The mode choice component is important to freight modeling because it can be used to evaluate the interaction between modes and shipment decisions, assess spatial policy issues, and generate elasticity estimates (*6*). A few of the examples discussed in the previous sections (e.g., SAM, ODOT) use aggregate mode share models in their four-step framework. These models estimate the share of commodities utilizing a specific mode between zones rather than considering a specific freight mode as a discrete choice made by a decision-maker such as a shipper for a given shipment. The latter approach is referred to as a disaggregate mode choice model, which is increasingly being implemented across regions. The disaggregate approach is recognized to be more behaviorally representative of the freight mode choice decision made by the shipper (decision-maker) taking the producer/consumer/shipper and the commodity characteristics into account but comes with significantly more data and computational needs.

Aggregate Mode Share Models

Description

The aggregate mode share models primarily utilize the transportation costs associated with moving a particular commodity across analysis zones as a major factor in estimating the share of that commodity to be transported using a given mode. The unit of analysis in this model is the mode-specific share of a commodity flowing between a pair of zones. One of the initial aggregate mode share model specifications proposed by Winston (*7*), referred to as the modal split or aggregate logit model, is as follows:

$$log\frac{S_j}{S_i} = a_0 + a_1(P_i - P_j) + \sum_{k=2}^{K} a_k(X_{ik} - X_{jk})$$

Where:

S = Market share of mode i, mode j.
P = Price of moving the commodity using mode i and j.
X = Variables such as average transit time between the modes.

This simple model structure facilitates empirical analysis but does not account for individual shipper behavior and restricts calculation of cross-elasticities of probabilities of choosing alternate modes. More specifically, a firm's choice of mode for shipment is influenced by several other factors, such as freight rates, delivery time reliability, transit times, shipment security, and carrier preferences. Considering these deficiencies, neoclassical aggregate models were born. In these models, transportation price is introduced as an attribute along with other factors such as shipment characteristics. In this model, the demand for freight transportation (X) by a given mode (i) is calculated as:

$$\frac{\partial C}{\partial P_l^i} = X_l^i(Y, q, w, P_l)$$

Where:

C = Total costs incurred.
Y = Output.
q = A vector of shipment characteristics.
w = A vector of factor prices except transportation prices.
P_l = A vector of transportation prices of the freight mode.

The neoclassical model estimates share of expenditure by transport mode and consists of two types: total flow approach and relative flow approach. The total flow approach uses regression-based statistical methods for calculating an overall measure of freight travel demand, whereas the relative flow approach looks at the proportion of freight traffic by mode using regression methods to model the relative flow of a mode against another (*8*).

Model Examples

The most widely known model of this form is the FAF model. The FAF is an aggregate mode share model produced by BTS and FHWA. It is primarily based on CFS data, along with international trade data from the U.S. Census Bureau and data from other sectors. The current FAF model is FAF5 based on 2017 as the base year; projections from these data are available for 2018–2019, and forecasts are available for 2020–2050 in five-year increments. This model reports the flows in terms of tonnage forecast by origin, destination, commodity, and mode.

Advantages and Disadvantages

Aggregate models are highly adaptable and integrate well with other models. Moreover, these models are not data intensive, are easy to use, and apply well to commodity, time, and cost aspects of freight demand. However, due to the aggregate nature of these models, they are not behavioral. Moreover, aggregate mode share models consider a limited number of variables, which makes them less sensitive in nature. For instance, they do not consider route choice and are not sensitive to price or other service-related variables.

Summary

In the absence of detailed shipment data, aggregate mode share models can be used to calibrate an overall freight model. They integrate well with other models and are ideal for nonbehavioral studies such as long-haul mode share analysis. The aggregate nature of such models has several advantages but lacks in scenario planning.

Disaggregate Mode Choice Model

Description

Disaggregate mode choice models, as the name suggests, are more aligned with representing decision-maker behavior such as that of individual shippers or firms making freight mode choice decisions for their shipment. Unlike the aggregate models, disaggregate mode choice models can capture the influence of the factors that influence choice decisions. They also allow for developing a better understanding of the competition between modes and assessing effects of market elasticities more accurately. Across freight literature, there exist two distinct forms of disaggregate mode choice models: inventory-based models and behavioral models. Each of these models incorporates characteristics of the mode, firm, consignment, and shipment characteristics that affect the mode choice decision.

Inventory-Based Models

The inventory-based approach attempts to model the production and logistic decisions of the firm. Baumol and Vinod (*9*) introduced this model to understand mode choice from the perspective of understanding the influence of shipment mode choice on inventory, with inventory being the safety stock stored at a consignee location to be used to serve demand in case the shipment is delayed. In this approach, the optimal mode choice accounts for the freight rates, speed, service reliability, and en-route shipment loss. Using this information, the approach develops an abstract mode choice model, wherein the mode that yields the optimal cost for the shipper becomes the likely mode, with cost being calculated using the following function:

$$C = rT + utT + \frac{a}{s} + ws\left(\frac{T}{2}\right)$$

Where:

C = Expected total annual cost of handling a commodity.
r = Shipping cost per unit of a commodity (e.g., tons), including freight rate, insurance, etc.
T = Total amount of commodity transported annually (i.e., also the quantity demanded).
t = Average time required to complete a shipment.
s = Average time between shipment.
u = Transit cost per unit per year (includes cost for deterioration + loss).
w = Warehouse holding cost per unit per year.

Considering production-related variables with mode choice decisions (e.g., shipment size vs. mode choice), this model type allows analysis of level of service on logistic costs. Also, the model predicts the expected total annual variable cost of hauling commodities across the modes, explaining the trade-offs between freight rates, speed, dependability, and en-route loss. According to Baumol and Vinod (*9*), the optimal choice from the perspective of an inventory manager (shipper) is opting for fast and reliable service that reduces the cost of inventory. More recent research suggests that this model well represents the real-life decision-making process (*10*) and is also capable of analyzing the introduction of a new transport mode, but the associated data are not as widely available to be implemented.

Discrete Choice Models

In contrast to the inventory-based models, the discrete choice models based on random utility maximization (*8*) have seen much wider use as both a stand-alone model and a component model within the four-step sequential framework. Specifically, these models represent a shipper or firm's shipment decision considering the characteristics of their commodity along with the transportation mode choices available for that segment. A form of this model, the incremental logit model, was utilized for aggregate mode share analysis discussed in the context of the TxDOT SAM model earlier in this review. At a disaggregate level, these model forms are used to estimate the shipment choice of firms utilizing a set of explanatory variables across modes such as transportation costs, travel time, commodity value per ton, etc. These variables are primarily fed as input to estimate the model of the following form, which could be used to arrive at probability estimates for each mode choice alternative for a firm shipping a given commodity, with the highest probability being for the mode with the highest (lowest) utility (disutility):

$$P(m) = \frac{exp(V_m)}{\sum_{n=1}^{N} exp(V_n)}$$

Where:

P(m) = Probability of the given choice (*m*) being chosen by the decision-maker.
V = Utility of a choice or alternative, the sum product of explanatory variables and their parameters.

m = Choice or alternative for which a probability of selection is computed.
N = Number of choices or alternatives available for a given decision-maker.

Using the above fundamental concept, a variety of discrete choice models have been applied in freight model choice analysis development, ranging from binary logit, to multinomial logit, to nested logit models, to jointly estimate shipment and mode choices.

Model Examples

FHWA's Second Strategic Highway Research Program (SHRP2) based models developed for Wisconsin Department of Transportation and the Maricopa Association of Governments (MAG) have incorporated some elements of these discrete choice models within their broader, more advanced activity-based model framework. The MAG model implements a disaggregate mode choice model within its supply chain framework. In this framework, first the firms or business establishments (decision-making agents) are synthesized for a given study area and period of interest. Using this input, the supply chain step of the MAG model implements an (a) supplier selection model, and (b) joint model of shipment size and transportation mode choice.

In the supply chain step, first the supplier selection model is implemented by rank ordering a list of supplier businesses for each consumer business in the market and picks the highest-ranked supplier for a given buyer. The variables considered for ranking on the buyer side include employment size and demand, and the supplier side variables include distance, selling price, and production amount. This model is implemented utilizing the Roth & Pearson Algorithm, which was used first to match potential employers and employees using medical residents and hospitals as a case study (*11*). In the MAG model, the supplier selection model outputs an annual firm-to-firm commodity flow reported in tons along with detailed characteristics of the buyer and seller firms (businesses).

Using the output from the above step, a joint shipment and mode choice model is implemented. In this step, first the shipment size of the commodity flow between each pair of businesses (supplier to buyer) is categorized into small (< 150 lb), medium (150–1499 lb), large (1500–34,999 lb), and very large (35,000+ lb) categories (*12*). These shipment sizes are then jointly modeled as a discrete choice along with the transport mode (which includes rail, truck, and air modes in the MAG model). They are jointly modeled because research found that the size of shipment significantly influences the choice of transport mode, with shipment size comparable to a given freight mode likely to result in that given mode being chosen (*13*).

The above models require a diverse array of data sources (IMPLAN, FAF, network distance, and transportation infrastructure data), and significant work is required as part of the data transformation process. This regional effort in the MAG model is a one-time model development effort. More importantly, the time required to execute each of these model components ranges in the order of days, particularly executing the supplier selection model. This methodology is instructive, but TTI researchers feel that run-time could be significantly reduced by altering the run criteria at the cost of affecting the resulting outputs, which would need to be further calibrated and/or assessed for accuracy.

Advantages and Disadvantages

Disaggregate mode share models are policy sensitive, and due to their disaggregate nature, are widely used for scenario planning. For instance, disaggregate models can forecast the effect of change in gasoline prices, an increase in congestion, or development of a new distribution facility on the travel patterns. These models also integrate well with other models. However, these models are very expensive to build and have large data needs. Though behavioral data can be collected by surveying shippers and carriers, such surveys can be very expensive to conduct. Moreover, these models are less adaptable than aggregate mode share models.

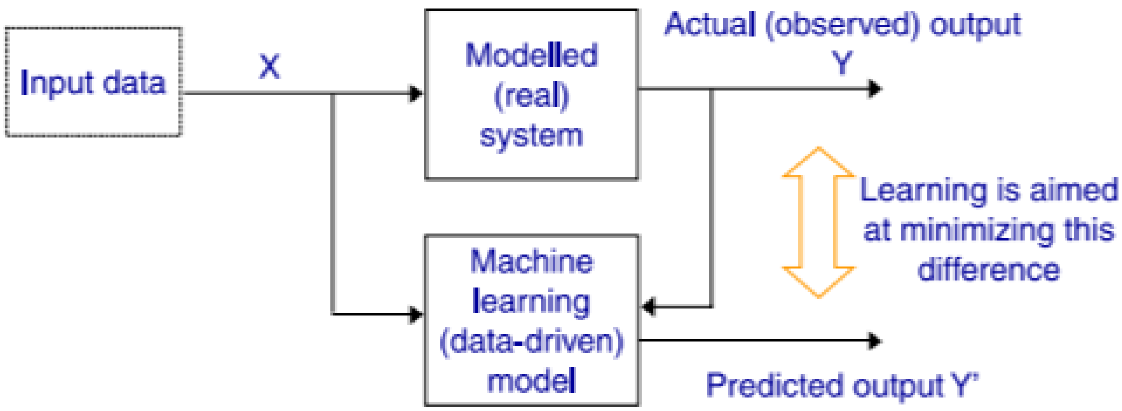
Summary

Disaggregate mode share models are more accurate than aggregate mode choice models due to their disaggregated nature; however, they are expensive to build and have high data needs. Nevertheless, these models are appropriate for scenario planning due to their sensitivity to policy changes or infrastructure changes. The ability to study urban freight traffic and scenario planning makes these models a strong candidate to complement the existing SAM in Texas. However, the resource demands and non-adaptability of these models must be considered.

DATA-DRIVEN MODELS

Description

Data-driven models help obtain more accurate predictions of the flow of traffic compared to their counterparts, particularly in urban areas. As shown in Figure A-1, Solomatin and Ostfeld (*14*) explained that the main principle of data-driven models is to minimize the error between the actual and predicted output from the models. In the context of transportation, that would be the predicted flow of traffic and its characteristics.



Source: (14)

Figure A-1. Data-Driven Modeling Approach.

Data-driven models typically involve the use of big data (passive data or tabular data) in conjunction with traditional data. While passive data such as location-based services data or GPS data help one observe and understand mobility behavior at an unprecedented level of granularity, conventional or traditional data sources such as travel surveys are richer in attributes and complement the passive data. The passive data are typically scaled to traffic or truck counts using origin-destination matrix estimation techniques.

Model Examples

MnDOT followed a data-driven approach in an urban freight study of the I-94 corridor. The corridor is heavily relied upon by freight stakeholders such as shippers, producers, receivers, and carriers, connecting businesses to markets. The study combined multiple sources of data, such as GPS passive data, InfoUSA data, census business pattern data, and average annual daily traffic (AADT) data, to generate truck counts, OD patterns, and truck travel patterns and other characteristics.

The study was comprised of a four-step methodology to generate truck trip volume: generating freight activity estimates at the zip code level using census data, allocating these activities to TAZs using InfoUSA data weighting measures, scaling the passive GPS data using TAZ estimates, and checking the results against AADT to make further adjustments. This approach could be considered an enhancement of the OD trip table factoring methodology but using more recent passive data. This project did not exclusively use a data-driven model, but understanding the method used is valuable because its application in urban freight planning has potential to be incorporated into other freight modeling efforts.

Advantages and Disadvantages

Data-driven travel models are rich in data and therefore facilitate several what-if scenarios, such as the impact on traffic due to route disruption, relocation of facilities, etc. Due to their high spatial resolution, these models make it easier to study traffic at a more granular level. Moreover, the data obtained are more frequent and recent, unlike traditional data sources, so the models facilitate special event studies very well.

The largest limitation of the data-driven travel model is that one must be aware of the biases that the data might hold. Also, data-driven models are mostly applicable for short-term forecasts due to their data collection methods. Further, this modeling method is more applicable to understanding freight impacts on urban transportation networks than impacts on a larger regional or statewide basis.

Summary

Passive data in the field of transportation have become abundant in the last few years. It will be a missed opportunity to not incorporate such data in freight models. GPS passive data are usually derived from embedded devices and therefore have additional attributes such as weight or make of the vehicle. Further, these data sources allow one to gain a more current understanding of impacts across weight class and provide insights on distinct movement patterns based on their function (i.e., cargo, service, or delivery). This information has often been found to be lacking within the traditional freight modeling and forecasting framework. These attributes have lately become even more significant due to the growing impact such movements have had on the urban road network due to ecommerce growth.

Apart from the above, use of data-driven models also compensates for several of the limitations found in the commodity-based models. For example, passive data have the potential to capture short/local freight trips that are not captured in commodity flow data, such as trips from warehouses to distribution centers, drayage movements in the ports, service vehicles, and construction trucks.

GRAPH NETWORK MODELS

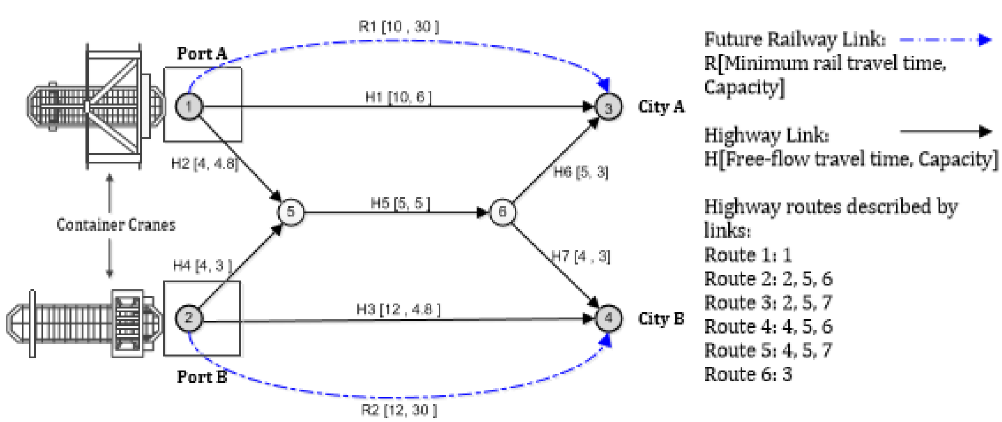
Description

Graph theory in mathematics involves the analysis of the relationship built from a collection of vertices (nodes) and links (edges) (*15*). This theory could be utilized within a model to represent a land use–transport network, where an edge represents a linkage between two locations that could be either a road or a rail line, and a node is the area of interest that could be either a road intersection, a block, or a town. This model framework could be applicable at the broader geographic level, like the IO models discussed earlier in this appendix used to analyze commodity flows. The commodity flows that are often reported in matrix format and produced using IO models or obtained from another external source such as Transearch or the FAF could be transformed into a graph database. A model could subsequently utilize this database to discover information and relationships and then visualize such relationships with the fewest resources. This could be further enhanced to evaluate policy scenarios at one or more levels, such as road restrictions, introduction of a new mode, economic and trade shifts, etc., on flows (existing or future projected flows) fed into the graph-based model.

Model Examples

This model framework has been increasingly adopted in other sectors, with only a handful of studies considering this approach in the freight sector, and more so in research than in actual practice. Jansuwan (*16*) developed one such model, specifically to analyze freight movement in the United States. As part of this research, two key quantitative metrics were produced using data from the CFS: route diversity and network spare capacity. Route diversity primarily reflects how many alternative routes exist between a given OD pair for freight flows, which is valuable in case of diversions or disruptions, whereas network spare capacity accounts for effects of congestion for freight movements.

Figure A-2 shows an example of a network showing linkages between cities, ports, and other nodes. The network can evaluate various scenarios using available information such as the effect of construction of a new road between ports, disruptions at a node (port), capacity augmentation of an existing linkage, or construction of a railroad. In effect, this framework could help evaluate the effects of economic, trade, and network policies and regulations with relatively fewer resources. It is not designed to produced metrics such as elasticities that could provide metrics of the influence of select variables such as transportation costs on mode choice preferences. Further, it cannot assess the influence of such infrastructure and cost changes on a shipper’s decision-making, which would require more of a disaggregate analysis.



Source: (16)

Figure A-2. Numerical Example to Evaluate Network Redundancy Measures.

Network theory could be used for understanding shipment decisions but would require effort and investment in acquiring detailed shipper data. Unnikrishnan and Figliozzi (*17*) presented such a model utilizing data to understand freight decision-maker behavior under multiple scenarios, such as (a) severe disruptions, (b) frequency of uncertain scenarios, and (c) extent of travel of parallel facilities (other modes or carriers). The research considered that the choice of mode of travel is made by the decision-maker, and the cost incurred by that decision is dependent on three factors: transportation cost, travel time, and its reliability. The decision-maker continuously learns about these attributes based on the historical movement of the commodities from such linkages and then updates the probabilities of accessing such linkages based on the above attributes. Unnikrishnan and Figliozzi presented a case study using their methodology for various kinds of shipments, such as dry, refrigerated, and frozen products from a major distribution center to a chain of national food chain stores in Portland, Oregon.

Additional to the previous example of the application of graph network theory in transportation, Demare et al. (*18*) presented an international context of commodity movement using graph theory. The model involves several agents in the logistics context (i.e., providers, shippers, and various transport mode operators). Such a model might require a significant amount of private and publicly available data, which can be a resource-intensive effort.

Advantages and Disadvantages

Graph network models are quick response and therefore are ideal for scenario planning. The ease of creating or breaking linkages and augmenting or reducing capacity in graph networks is one of the biggest advantages of such models. Moreover, as is apparent from the above model examples, a graph-based modeling framework could be adopted across multiple use cases. However, graph network models represent aggregated data and thus are not ideal for behavioral studies.

This model framework could be further evolved to include multiple attributes, such as that of the transportation network and that of sub-regions within each region, to account for their influence on commodity flow. From a policy perspective, this framework could be used to evaluate economic as well as transportation-related impacts on commodity flow. One could assert a failing link or node and attempt to examine the extent of diversion or shifts in demand across the entire network with relative ease compared to traditional methods. None of the existing models discussed previously in this appendix provide the ability to undertake such an exercise. However, a graph-based model does not allow one to understand how shippers make decisions, how a decision could affect long-haul mode choices, or the influence of urban freight movement resulting from truck route restrictions.

Summary

Graph-based modeling frameworks are highly versatile and have various potential applications in transportation studies. These models could be valuable for planners to evaluate the potential costs/benefits associated with infrastructure investments based on how well connected given OD pairs are and what kind of commodities utilize such links. They could also be used to test scenarios of disruption and the related impact at the network level as well as the economic impacts at OD nodes. Graph-based models have a high potential to complement the existing Texas SAM because they could serve as a quick response scenario planning tool.

TIME SERIES MODELS

Description

Unlike the models discussed so far in this review, time series models are utilized to understand freight-related impacts along a specific roadway segment or corridor. These models are developed with the assumption the future impacts would not be significantly different from the impacts observed in the past (*19*). However, this might not necessarily be true, particularly if the influence of exogenous factors such as shifts in economy or trade patterns are considered. Thus, even though these models could be used for short-, medium-, and long-term forecasting, they are most often recommended for short-term analysis.

Several different time series models have been developed, ranging from the simple trend model, to the moving average model, to the autoregressive moving average model (ARIMA). These models can be used for capturing not just immediate trends but also seasonal patterns and special event effects. The simple trend model primarily assumes that the percentage change over time is constant but is distinct from growth factor approaches, where it is assumed to be constant across time (*20*). The moving average model is a bit more sophisticated in that it averages the estimates across nearest neighbors in terms of time. This allows the model user to smooth out any seasonal or weekly fluctuations that might result in spurious outcomes. The ARIMA model further builds on this concept, not only smoothing the results using the averaging technique but also introducing a time-lagged dependent variable as an independent variable into the model to account for its effect on the present period.

Not accounting for these aspects could result in spurious causal relationships between variables. This accounting is done to mitigate the variability in the statistical estimates (means and variance) of regression models estimated across time, which could adversely affect the ability to forecast. Intuitively, one would want to have a stable estimate of the present state before predicting a future state. These models do not require data from diverse sources but do require data from a handful of sources over longer time periods. For example, it is recommended to have at least 50 data points for ARIMA models, without which the model might not produce satisfactory results.

Model Examples

Horowitz et al. (*20*) utilized time series data in their heavy commercial vehicle forecast for a section of I-40 in New Mexico using linear regression. The model used annual income, gas price, and residential construction cost as independent variables to estimate traffic on the interstate with an R-square of 0.8. The large negative y-intercept in the equation is due to using a four-digit year in the trend term.

$$hc = -28000 + 15y - 0.12d - 0.08g + 0.078c$$

Where:

hc = Heavy commercial traffic on I-40 (dependent variable).
y = Year.
d = U.S. disposable income.
g = U.S. cost of gasoline.
c = New Mexico's residential construction cost.

In comparison to the above, Garrido (*21*) developed a more sophisticated spatiotemporal variant of the ARIMA model. This model was used to forecast and understand the elasticity in volumes across multiple parallel facilities (eight bridges connecting Texas and Mexico) over a three-year period. The Florida Department of Transportation also employed the ARIMA model to forecast volume on roadways adjacent to ports. In this model, truck traffic volume data collected from roadways were used as the dependent variable representing inbound/outbound traffic as the trip generation potential. This independent variable was then regressed against data specific to the port, such as data on cargo vessel movement including total imported and exported freight container units. This model can forecast daily and hourly truck movement to/from the port for future years.

As is apparent from each of these examples, these models are specific to evaluating a particular site or link. Thus, these models might not capture effect of any other exogenous variables (such as shift in trade, port choice, or economic condition). An exception to this effect is a regression-based model using time series data developed by the Alabama Department of Transportation. In this method, the annual diesel fuel consumed was conceived as a dependent variable, a surrogate measure of freight activity in the regression function, along with several other historical independent variables such as value of shipments, employment by industry, labor force, personal income, and state and regional gross domestic product (GDP).

This model was to an extent able to capture the socioeconomic effects through state and regional GDP variables. Further, in terms of linkages, this study utilized the output from this model (i.e., diesel fuel consumed) to subsequently arrive at estimates of truck use (by category) for the state using imputation methods by considering the diesel consumption rates across different commercial vehicles operating in the states and then subsequently the corresponding vehicle miles of travel from such vehicles on the state's roadway network (*22*). Nonetheless, these forms of models are not as widely in use and might not be able to capture some commodity flow effects or the subsequent mode choice behavior that states often seek to understand.

Advantages and Disadvantages

Time series models are simple and quick but also have the potential to turn into a sophisticated model based on the availability of data. Time series models are ideal for short-term forecasts. However, time series models require complex time series data with long series data points (*1*), which could pose a challenge when looking at annual level time series data. Additionally, in many cases, such long series of observed data are not readily available, which sometimes leads modelers to use only a few series of data. Furthermore, the model type assumes that past trends are indicative of future activity and, as a result, are less able to account for special events, policy changes, changes in modal services (*6*), or changes in trade patterns that affect freight demand.

Summary

Time series models are most appropriate for scenarios that require quick and low-maintenance modeling. In transportation planning, common uses of time series models are in corridor planning and forecasting, quick response growth estimates, and traffic impact assessments. Most of the time series models tend to be case or research specific and require significant expertise to be practice oriented. Furthermore, they often involve analysis of univariate data, making them difficult to be applied to understand policy sensitivity. Even those models that do account for exogenous variables as an econometric framework need to exercise caution, especially if the process involves introducing another set of time series data.

OTHER MODEL TYPES

The following models are applied by industries to optimize their production and distribution in terms of resources such as time, cost, and distance. A few of these models, such as the supply chain logistics, network design, and scheduling and routing models, are not applied in the public sector (*5*). However, it is essential to understand the fundamentals on which these models are based to get a better understanding of the decision-making priorities of the private sector, which could be of value in informing models developed for the public sector.

Supply Chain and Logistics Models

Supply chain and logistics models look at the entire freight transportation system as a whole with interaction among multiple factors/players that affect freight demand—producers, shippers, carriers, consumers, and government—and capture the upstream and downstream relationship between the different players (*8*). These types of models are based on the principle of maximizing satisfaction and minimizing transportation costs within modes by optimizing the location of activities within a network. These models attempt to estimate the total logistic cost of shipping by incorporating direct transportation costs and inventory costs based on lot sizes and service profiles. Additionally, these models assume that the customers opt for the lowest-cost shipping option.

There are two general types of logistics models: freight network equilibrium and spatial price equilibrium. The former focuses on shipper-carrier interactions and the latter focuses on producer, consumer, and shipper interactions. In freight network equilibrium modeling, the generation of trips from each region is assumed to be known. Shipper transportation needs are determined and then routed to minimize the carrier's costs. Spatial price equilibrium models estimate trip generation and consumer and producer behavior using the information on commodity supply and demand functions. The spatial equilibrium principle states that if a commodity flows from region A to B, the price of the commodity at region B should be the sum of the price of the commodity at region A and the cost of transportation of the commodity from region A to B. If the price of the commodity in region B is less than the stated sum, then the commodity would not flow from A to B.

In summary, supply chain and logistics models provide helpful information on freight trip chaining and mode choice decisions; however, these models can overstate modal opportunities due to the inability to filter out unavailable modal options if the data on modal service options by commodity types and shipper's set of customer destinations are unavailable. Also, these models are complex to implement and are very specific to an industry sector or goods productions, and thus are not very adaptable. These models are not often used in traditional transportation planning applications and are generally more applicable to the private sector/individual firms.

Network Design Models

Network design models are private-sector models that are used by firms for locating factories, distribution centers, or warehouses for optimizing service in terms of cost, time, and distance by considering the location of activities in the network. Network design models can estimate the sensitivity of mode and route to various cost and time factors. Also, the models are useful in determining the load of each mode on the transportation infrastructure. However, these models are very challenging due to their scale and the interdependency between various players in the system. Also, the data needs for these types of models are very high, so they are not popular among public agencies.

Routing and Scheduling Models

Like network design models, routing and scheduling models are primarily used in the private sector to optimize routing and frequency of shipments, and there is a lack of research in public-sector model application. These models aid in dynamic routing and scheduling using real-time information by optimizing the route to minimize vehicles, travel distance, and labor. Even though this model type is not frequently used in the public sector, the information on routing and scheduling from such a model could help estimate internal freight trips, which seems to be lacking from the commodity flow models.

CONCLUSIONS

Freight analysis models have evolved over time in terms of both their behavioral representation and their application for project-specific analysis. Like household travel demand models, the most widely known model among them is the sequential four-step travel demand model involving trip generation, distribution, mode split, and network assignment.

In the freight context, the trip generation and distribution steps are implemented using commodity flows produced by econometric software such as IMPLAN that utilize census input/output tables as the primary input. These forms of models are also thus referred to as commodity-based input-output/four-step models. The trip tables generated using commodity flow data (e.g., Texas SAM) allow one to form linkages between the economic and transportation sector but come with additional data and software service needs. The flow factor method, in contrast, trades this linkage for ease of maintenance by utilizing already available freight trip tables (vehicle data, shipper surveys, etc.). For its interim freight model, ODOT implemented this method using an external data source (Transearch) and then continued to model the mode split and network assignment step. Another prominent flow-factor-based freight analysis tool is the national FAF. This tool is used more as a reference database and benchmarking tool than a modeling application. This step of the sequential four-step process primarily serves as a tool to analyze commodity flow across study areas for economic studies and is also used as an input to understand the potential effect on freight transportation modes.

Freight-related transportation impact is attributed through estimation of the extent of commodity flows between regions and their potential choice of transport mode. This is accomplished in the four-step process utilizing the aggregate mode share models, and more recently using disaggregate mode choice models. The aggregate models primarily reflect the potential shift between modes based on generalized transportation costs and do not consider a shipper or firm’s shipment decision-making process. A shipping decision might be tied more to the cost of shipment, reliability of service, and time sensitivity and value of the commodity being shipped. Thus, to take these factors into account, recent developments in freight modeling have been moving toward the implementation of disaggregate mode choice models. These models simulate a firm or shipper’s (decision-maker’s) behavior considering the above discussed characteristics. Disaggregate mode choice models are promising in terms of capturing the factors that influence a firm’s shipment decisions but also come with additional computational complexity and the need for more granular data. Overall, the models developed for this step primarily could be used for modal share analysis and subsequently be used to assign them to corresponding transportation networks to understand their network-wide impact.

The output from freight network assignment is mostly used to understand through movements from a region or the commodity-based impacts along major freight corridors for economic development efforts. The sequential four-step model is found to fall short for project-specific analysis (a special generator or corridor) and assessment of urban commercial freight (delivery, services, drayage, etc.) movement. Much of the site-specific analysis is often implemented using time series models utilizing local travel data (e.g., historical traffic counts, site-specific variables such as freight movement at ports, etc.) for longer time periods. Because these models are project specific and developed based on local data, they cannot be used beyond this scope and thus are only useful for understanding short-term forecasts; they do not account for several other exogenous factors (e.g., trade, economy, etc.). In terms of understanding urban freight movement, the more recent data-driven models seem to hold promise in that the data sources can help understand local freight movements at the network level and over longer time periods. This helps one assess the impact of potential local policies such as parking regulations, hours of operation, land use development impacts, etc. MnDOT (*23*) implemented an urban freight study analyzing the I-94 corridor utilizing multiple data sources to understand the location of major freight activity and movement of goods. This data-driven model, just like the time series models, is project specific and could not be used beyond that scope since it does not incorporate economic or modal elements.

In addition to the above models, graph network-based models include a promising method that has not been explored much for freight analysis except in research. This model type is built on the concept of nodes (e.g., area of activity) and edges (e.g., roadway or rail connecting such areas) and, in theory, aligns with the nature of freight commodity flow data. This framework in essence could be used at a minimum to undertake a what-if analysis of commodity flow data with the least number of resources. Further, it could be incrementally enhanced using additional attributes such as modal network characteristics as well as addition of finer geographic analysis areas such as ports, distribution centers, and rail facilities. Each of these enhancements could be undertaken without the need for development of a parametric model and could be used as is to understand the potential shifts in commodity flow under different economic and transport scenarios. Jansuwan's (*16*) research illustrates some of these scenarios utilizing CFS data, which reinforces the potential value of this tool in terms of understanding the relationship between freight, transportation, and economy at a regional level. However, the model cannot be used to undertake analysis such as estimating modal shares or performing link-specific analysis.

SELECTION OF A RECOMMENDED FREIGHT MODEL TYPE

Based on the review of the prominent freight modeling methodologies, the research team determined that there is no one solution for freight modeling, and a trade-off usually exists when it comes to model characteristics such as adaptability, integration, data needs, etc. Table A-1 summarizes the potential value/trade-off associated with each of the discussed models in terms of data needs, data costs, and model complexity. Additionally, every model has at least one trade-off or shortcoming, which makes the process of selection of a model highly subjective. For instance, while disaggregate mode share models are highly sensitive and ideal for scenario planning, they are costly, data intensive, and low on adaptability. Similarly, aggregate mode share models rate low on cost and data needs, and they are highly adaptable, but they are not an ideal choice if stakeholders are looking for a model appropriate for scenario planning.

Table A-1. Freight Model Comparison.

Freight Model Types	Aggregate (A) or Network (N)	Complexity*	Data Needs*	Adaptability*	Scenarios*	Integration*	Maintenance/ Data Costs*
Commodity-Based IO Models	N	H	H	M	M	M	H++
Control Total and Trip Table Factoring**	N	H	M	M	L	M	M
Aggregate Mode Share Models	A	M	M	H	L	L	L
Disaggregate Mode Share Models	N	H++	H++	L	H	H	H++
Time Series Models	A/N	L	L	L	None	L	L
Data Driven**	N	M	M	L	M	M	M
Graph Network**	A/N	M	M	M	M	L	M

*L=Low, M=Medium, H=High, High++=Very High.
**Models not included in SHRP2.

The identified gaps revealed the need for additional analysis tools to supplement the current Texas SAM. More specifically, an analysis toolkit that can be used to analyze urban commercial freight activities and tie freight activities at concentrated trade areas such as ports or industrial areas to higher-level geographies of commodity flow is needed. Initial thought was that the latter could be undertaken using graph-based models, which could be developed incrementally with existing commodity flow data and be further augmented with supplemental data sources such as network and sub-area node characteristics. Further, the urban commercial freight impacts could be investigated using a data-driven modeling framework, which could be developed through synthesis of traditional commercial travel data with emerging passive and land use data sources.

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APPENDIX B: DATA TRACKING AND TRACING TECHNOLOGIES

DATA TRACKING AND TRACING TECHNOLOGIES

Introduction

This appendix offers a brief overview of freight metrics, which are the basis to determine data and information needed for modeling, and a review of the most current and promising freight data sources. These data sources were identified by the research team at the outset of the project during the targeted literature review.

Freight Metrics

Metrics are a key component of modeling. Typically, freight metrics are based on four basic data elements or primary indicators (*1*):

- **Travel Time—**This data element refers to average speeds and relates these average speeds to some benchmark figure—typically free-flow speeds—thus providing information on how much longer, on average, it takes to travel during actual conditions compared to optimal traffic conditions.
- **Travel Time Reliability—**The concept of travel time reliability indicates how consistent travel conditions are. This is related to the concept of travel quality, which contributes to smooth and predictable travel conditions. Traffic professionals have come to recognize the importance of travel time reliability because it better quantifies the benefits of traffic management and operation activities than do simple averages.
- **Origin and Destination—**OD is an element that determines tours or routing and is closely related to travel time and distance.
- **Commodity (or Cargo) Volume and Value—**This element provides information on the amount of goods handled between the origin and destination points throughout the transportation network. It offers a supply chain perspective by helping to understand the agility of supply chains.

Some additional basic data elements have also been applied, such as cost, which is sometimes used as a primary criterion for measuring performance and economic feasibility in supply chain operations, depending on the focus of analysis. Existing freight metrics and measures, which include freight trips, tonnage, OD, and tours or routing, are related to the basic data elements of interest (*2*). For instance, OD and tours or routing are closely related to travel time and distance, while tonnage is related to value and volume. From these basic data elements, four main types of freight variables can be distinguished in relation to modeling, as summarized in Table B-1.

Table B-1. Main Types of Freight Variables Related to Modeling.

Variable	Description
Vehicles miles traveled	Distance a vehicle travels
Freight trips	Number of vehicle trips with a previously specified distance
Tonnage	Transported commodity weight
Volume	Transported volume in number of vehicles

Existing Freight Data Sources

Based on the metrics variables and data elements, this section presents a review of appropriate data sources for freight transportation modeling. An overview of existing data sources that can produce valuable information when used effectively and in an innovative process that draws upon each source's strengths is included.

Private-Sector Data Providers

There are several recognized data providers in the private sector at the national level. These providers use multiple data sources and have proprietary processes to aggregate and forecast freight flows that each have inherent strengths and limitations that must be accounted for in their datasets. These providers are discussed in the following subsections.

Transearch

Transearch is a planning tool developed by IHS Markit that allows transportation planners to predict U.S. freight flows over 30 years by origin, destination, commodity, and transportation mode (*3*). The Transearch dataset covers the following data elements:

- Outbound, inbound, intra, and through shipments by geography (172 Bureau of Economic Analysis economic areas/3,000+ counties for the United States, state-level detail for Mexico, and province/municipal data for Canada).
- Volumes routed along individual trade lanes or corridors.
- Tonnage, value, and units of shipments.
- Truck, rail, waterborne, and air (submode detail available for rail and truck).
- 340+ commodities.
- Canada and Mexico cross-border flows.

Datamyne

Datamyne, founded in 1992, is another private initiative that became a top-ranked provider of international trade data (*4*). The dataset is driven by U.S. trade with more than 230 markets worldwide. Datamyne data are extracted from import and export manifests and customs clearance documents (*4*). Manifests yield details of each shipment: parties to the transaction, logistics, cargo descriptions, and volumes. The data are then enhanced with additional information, including calculated values of incoming shipments. Datamyne's data cover 100 percent of U.S. waterborne imports and approximately 94 percent of U.S. containerized exports.

HERE Routing API

HERE is a multifaceted company providing mapping data, technologies, and services to the automotive, consumer, and enterprise sectors. HERE provides GPS technology to automobile manufacturers for their built-in navigation systems. In addition, several external GPS devices are built and served from the same HERE GPS technology. HERE collects data from those GPS devices installed in many passenger and commercial vehicles around the world. Due to confidentiality of individual location data, no information on travel time algorithms is made available.

HERE provides historical, real-time, and estimated travel data through one of its products called Routing API, which provides data from several regions in the world including additional information on routing, traffic flow, average speed, accidents, road accessibility, etc. Routing API can handle requests in three transportation modes: car, truck, and pedestrian. In the case of truck routing, Routing API provides information on whether the route is accessible by trucks only or mixed traffic.

The only required input parameters for Routing API are origin and destination in the form of coordinates. Once the route is calculated, a set of waypoints is returned as the optimal route. Each one of those waypoints is also expressed in coordinates, which are matched with the waypoints defined in the HERE network. The default departure time is the time when the request is made, but it could be reset to a past or future time. There is no information on what is the range of the departure time or the frequency of computation. The provided departure time is considered as local time based on the point of origin.

Routing API is available through account registration on the HERE website. Each account is allowed 250,000 free OD requests per month, with cost increments of 1,000 requests per $1 in charges thereafter. Development support was limited and community feedback was scarce at the time of this review. Technical documentation on product use is available through the HERE website, but data support or source verification is not available. For instance, travel times provided by HERE do not offer any reliability measures (i.e., ground truth comparison), such as confidence intervals and travel time variation, nor information on sampling methods or sample features such as size of the data files.

Google Maps

Google is the leading company in personal travel routing information. Through the Google Maps app, Google reached 154.4 million users in 2018 (*5*). This app collects data from personal devices such as cellphones or tablets that are GPS equipped. Google collects data and updates the data continuously to provide estimated travel times. Due to confidentiality constraints, no information on travel time algorithms is available.

Google Maps offers a data service through Google Cloud Platform. Services like routing, mapping, and geocoding are accessible to anyone with a Gmail account. Massive amounts of travel time information are available through an application called Distance Matrix API. The minimum requirements for querying a distance matrix is origin and destination, both expressed in latitude and longitude coordinates. In addition, the application allows the user to specify travel mode, route restrictions, arrival or departure times, and more.

Google Maps provides travel time estimation for departure times at the time of the query or in the future, but not in the past. That is, Google Maps historical data are not available for public use. Moreover, because the collected GPS data come from mobile devices, the information provided by Google Maps is limited to transit, biking, driving, or walking modes. The vehicle type cannot be distinguished between commercial and private vehicles. The only way that truck flows may be inferred is by querying an OD pair that is known as a predominantly commercial route, and thus it would serve mostly or exclusively trucks; then travel times provided by such a query could be assumed to be for trucks.

The most accurate information issued by Google Maps is the present real-time information because estimated travel time accuracy decreases as departure time is further into the future. However, users can choose the traffic scenario to be used for estimation from three options: best guess, pessimistic, and optimistic.

All Google Cloud Platform products, including Distance Matrix API, are accessible to anyone with a Gmail account. Each account is credited with $200 every month to be used based on user needs. Each OD request is considered an element, and 1,000 elements has a total cost of $5. Technical documentation on the APIs can be found on Google’s websites and community forums (*6*).

Business-to-Business Data

Some private-sector companies can provide data that can be used to better understand how goods are traversing a multimodal freight system. These data are collected through tracking sales, purchasing, shipping, and/or delivering transactions of goods. A good example of this type of B2B data is Quetica.

Quetica is a private company providing consultancy and financial supply chain solution services; it collects bill of lading information from many Fortune 500 companies that is then aggregated into its datasets, enabling Quetica to provide routing from standard routing models (*7*). This type of B2B data, along with B2B payment data, could be useful for assessing different freight transportation behaviors.

National Performance Management Research Data Set

The NPMRDS historical traffic speed dataset covers the entire National Highway System. It includes observed measurements, collected 24 hours a day, and provides the user with average travel times in five-minute intervals in three ways: freight trucks, passenger vehicles, and all vehicles. It also provides the averages of 10-minute, 15-minute, and 1-hour intervals (*8*). Procured and sponsored by FHWA, the NPMRDS relies on ATRI as a trusted third party for freight data, which are formed by over 600,000 truck probes, collecting GPS data for 3 billion position points a year of primarily long-haul trucks on the interstates (*8*). Specifically, the data represent a strong truck sample (approximately 30 percent of registered Class 6, 7, and 8 trucks). However, short haul, drayage, and delivery are less represented, and the data offer no commodity information (*9*).

One important advantage for Project 0-7037 purposes was that the NPMRDS has included additional roadways near border crossings with Canada and Mexico since 2017. However, the temporal and geographical coverage is still very limited on the Mexican roadways. There are other data sources that offer some information on border flows, such as HERE and Google Maps. However, those sources are included under B2B given its funding and collection features. Another advantage due to FHWA sponsorship is that the NPMRDS is available to federal agencies, state departments of transportation, and MPOs.

Regional Integrated Transportation Information System

RITIS is an automated data sharing, dissemination, and archiving system that includes many performance measure, dashboard, and visual analytics tools that help agencies gain situational awareness, measure performance, and communicate information between agencies and to the public (*7*, *9*). RITIS consolidates, standardizes, and fuses disparate data sources and systems into a platform for use by a wide range of users and applications (*10*). RITIS is hosted by CATT Lab, a user-focused research and development laboratory at the University of Maryland.

RITIS consolidates data from various sources, including state agencies, device manufacturers, and third-party data providers like HERE, INRIX, and TomTom Navigation (*10*). RITIS is available to organizations sponsored by RITIS, but memberships are also available for purchase by transportation organizations that conduct research in operations or planning, along with those that provide traveler information.

FHWA Freight Analysis Framework and Commodity Flow Survey

The objective of the FAF is to integrate data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation. The FAF is publicly available and also provides information on import and export flows (*11*).

The FAF uses data from the CFS and international trade data from the U.S. Census Bureau. The CFS is the primary source of national- and state-level data on domestic freight shipments by American establishments in mining, manufacturing, wholesale, auxiliaries, and selected retail and services trade industries (*12*). The FAF incorporates data from agriculture, extraction, utility, construction, service, and other sectors (*13*). The CFS information is collected every five years. Based on the CFS, the FAF has a base year and forecasts, but data are not continuous.

Bureau of Transportation Statistics

The BTS mission is to create, manage, and share transportation statistical knowledge with public and private transportation communities and the nation (*14*). BTS's major freight data sources are (a) the Intermodal Transportation Database (which includes data from the BTS/Census CFS); and (b) the National Transportation Atlas Database (which is a set of nationwide geographic databases of transportation facilities, transportation networks, and associated infrastructure, as well as statistics on the performance and impacts of the nation's transportation systems (*8*). BTS also provides summary statistics for incoming crossings at the U.S.-Canadian and the U.S.-Mexican border at the port level. Incoming crossing data are available for trucks, trains, containers, buses, personal vehicles, passengers, and pedestrians. Border crossing data are collected at border ports by U.S. CBP (*15*). All data published by BTS are available online through its website.

Port/Border Freight Data

Traffic flows that cross U.S. land ports of entry are an important part of travel demand. In 2019, more than 6 million trucks crossed from Mexico into the United States through land border crossings, carrying goods that are important inputs to U.S. manufacturing and for personal consumption (*16*). Typical data sources do not include these trips or freight flows. However, there are some data sources that do provide information at some level.

There is also a specific data source that provides real-time and historical information on border crossing flows: the Border Crossing Information System (BCIS), funded by FHWA, U.S. CBP, TxDOT, and other state department of transportation. The BCIS provides real-time and historical information on wait and crossing times (*17*). The BCIS obtains raw data from field devices using RFID technology to measure travel times between the RFID readers installed at major points of the U.S.-Mexico border crossing process. Usually during its trip across the border at the border crossing, a truck passes under two or more RFID reader stations. The RFID reader station detects the truck's tag identification number and makes a time stamp of the record. These data are processed to obtain travel times and wait times for each crossing. Travel times are updated every 15 minutes on the BCIS website (*17*). However, raw data are available and can be used to compute travel times on a different granularity.

CONCLUSIONS

Many of these data sources are not the first source of data, but they provide the most comprehensive collection of freight datasets. For instance, the NPMRDS relies on ATRI for freight data. RITIS retrieves data from third-party providers such as HERE, INRIX, and TomTom. The FAF uses the CFS and international trade data as the main components of data sourcing, and BTS's freight information includes the intermodal transportation and national transportation databases, along with statistics from the nation's transportation systems. One of the handicaps of these data sources is that some of the provided information may not be regularly and consistently available.

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APPENDIX C: INNOVATIVE FREIGHT TRACKING AND TRACING TECHNOLOGIES

INNOVATIVE FREIGHT TRACKING AND TRACING TECHNOLOGIES

Depending on the type of task performed on data, technologies can generally be categorized into three groups:

- Data collection.
- Data transmission.
- Data processing.

The reason for this taxonomy is that it allows a distinction of the technology's role in modeling. This is important because although modelers generally claim to use data stemming from collection and transmission technologies such as RFID or GPS, the reality is that modelers use data after they are processed, hence using essentially a combination of all technology types in the taxonomy.

Data Collection Technologies

Data collecting technologies gather data directly from the object being measured, whether it be the inventory item, the machines in a warehouse, or the vehicles carrying the products. These technologies are the first stage of dataset building.

Electronic Logging Devices

Many of the data collecting technologies include what are now called electronic logging devices. An ELD is a device "that is used by drivers of commercial motor vehicles (CMVs) to automatically record driving time and Hours of Service (HOS) records, as well as capture data on the vehicle's engine, movement and miles driven" (*1*). ELDs were mandated as part of MAP-21 (*2*) under the "electronic logging device rule" issued in December 2015, which requires the use of ELDs for the commercial truck and bus industries, aimed at facilitating a "safer work environment for drivers" (*3*). ELDs attach to a CMV to synchronize with the engine and record HOS, driving time, location, engine hours, vehicle movement, and miles driven.

Note that ELDs are not a technology but rather devices that use a range of technologies such as GPS or Bluetooth to perform their function.

Currently, several ELD providers exist. TTI researchers have made contact with two vendors and are now working on a partnership to leverage their data for planning and policy research.

GeoTab

GeoTab is a fleet management solutions provider with over 35,000 customers that collects more than 3 billion data points daily from its customers (*4*). GeoTab's data cover the continental United States and Canada since December 2017, comprising long and short haul as well as service and delivery trucks. Data are stored in six main tables: engine status data, GPS data, engine fault data, accelerometer data, trip data, and VIN decode data. Some of the most relevant variables for freight modeling are summarized in Table C-1.

Table C-1. Geotab's Relevant Variables for Freight Modeling.

Trip	GPS	Engine Status
Trip ID	Latitude	Vehicle active (idle or driving)
Start Time	Longitude	Total engine idle time
Stop Time	GPS Valid—whether the GPS log is valid	Odometer (reading)
Driving Duration	Ignition (ON/OFF)	Engine operational time
Stop Duration	Speed	
Distance	GPS Reason—reason the GPS log was generated	
Idling Duration		

EROAD

EROAD is also a fleet management service and ELD provider. EROAD is based in New Zealand and has a U.S. office in Portland, Oregon. The data universe of this vendor is smaller than GeoTab and totals 20,955 tracked units as of September 2018. EROAD's coverage is similar to GeoTab's, which includes the continental United States since 2017 of long and short haul as well as service and delivery trucks. EROAD generates event-level data that are typically aggregated to a temporal or spatial resolution that protects the privacy and commercial sensitivity of its customers. EROAD also provides a distribution of the industries and vehicle make and models for the aggregated data.

Table C-2 shows some of the most relevant variables for freight modeling. EROAD's data are presented in clustered form as part of the aforementioned aggregation.

Table C-2. EROAD's Relevant Variables to Freight Modeling.

Number of Vehicles per OD County/State per Cluster	Percentile Distribution of Time Stopped in Seconds at Each Cluster	Clusters of Parking Location along a Corridor	Distribution of Arrival Hours at Each Cluster
Cluster ID	Cluster ID	Cluster ID	Cluster ID
Start County	10th Percentile	Number of Events	Stopped Event Hour
Start State	25th Percentile	Polygon with Centroid	Number of Vehicles
Stop County	50th Percentile		
Stop State	85th Percentile		
Number of Vehicles	95th Percentile		

Electromagnetic Radio Frequency Identification

The general concept of radio frequency includes magnetic and electromagnetic fields. These fields define their range as near-field (magnetic) or far-field (electromagnetic). RFID is generally related to the far-field electromagnetic type, while the near-field magnetic is generally known as inductive since it uses inductive coupling as a power source. This difference is important because although commonly known RFID and inductive technologies are both radio frequency based, they differ in their range and power source (*5*).

There are two types of RFID technology, active and passive.

Active RFID

Active RFID tags have an internal power source and are usually battery powered. These systems use two main frequencies, 433 MHz and 915 MHz. Active RFID tags have very long reading ranges and substantial memory banks. They can be used in sync with GPS or WSN technology. Since active RFID tags are much more expensive due to their internal power source, these types of tags are usually used when tracking highly valuable assets.

Passive RFID

Passive RFID tags are much more common when used in the logistics supply chain. There are three working parts within passive tags: the RFID reader, RFID antenna, and RFID tags. Since passive tags do not have their own internal power source, these three components are necessary for successful usage. These types of tags are much more cost effective but do not have as wide of a reading range or as broad of a memory back as active tags. Passive tags run on three different frequencies:

- Low frequency (typically 125–134 KHz)—Long wavelength, short read range (approximately 1–10 cm).

- High frequency—Medium wavelength, medium read range (approximately 1 m).
- Ultra-high frequency—Short wavelength, long read range (approximately 6 m).

RFID tags are not limited to scanners like barcodes. These tags can be used in connection with other technologies, such as WSN, to transfer data (*6*, *7*, *8*, *9*, *10*, *11*).

Optical Codes

Optical codes store product information, which can be recovered when scanned. Optical code technology can be categorized as either linear barcodes, the most recognized, or matrix (2D) barcodes. Both barcode types have been implemented in many industries, such as retail or healthcare, to collect many types of data, such as parcel delivery (*12*). For instance, 2D barcoding have been used in logistics units such as warehouses, stores, and carriers to collect data on location, routing, and shipment details (*7*). Optical code technology will not be fully replaced by RFID technology because codes are easily emailed and printed, and the technology is much more cost effective than RFID. This type of technology is widely used in the logistics supply chain today.

Some of the benefits of using optical codes are:

- High accuracy with very few errors.
- Cost effective.
- Ease of access (emailing and printing).
- A mature technology that has been proven successful (*6*).

Inductive Technologies

As previously explained in the RFID introduction, inductive technologies use inductive charging on a charging station as a power source. Energy is gathered through inductive coupling via coils. Induction coils are used to create an electromagnetic field allowing for information dissemination and communication. Many technologies that are relevant to supply chain management (SCM) fall into this category, including:

- Near-field communication—Short-range communication usually used for asset tracking or communication between warehouse machines.
- Inductive loop detectors—Track when a vehicle has passed over the device.
- ZigBee and RuBee devices—Similar to RFID tags, but use inductive technology to collect data (*13*, *14*).

Weigh-in-Motion Systems

WIM systems use in-ground piezo-electric or quartz sensors to weigh and classify vehicles in live traffic lanes. This can be for statistical reasons related to asset management or for enforcement (*15*). FHWA has set standards for different WIM systems. Below is the specification of each type:

- Type I and Type II—These types of WIM systems are the most used systems today. Their goal is to collect data from passing traffic. Vehicle speed can range from 10–80 mph for a successful reading.
- Type III—These types of WIM systems have stricter requirements and are used on vehicles that are thought to be breaking weight limits. These systems can also run from 10–80 mph for a successful reading.
- Type IV—These systems are not approved for use in the United States. These are used for measuring weight enforcements and can be used from 2–10 mph (*15*, *16*).

Video Vehicle Identification

A video vehicle identification system is a nonintrusive traffic sensor technology that can be embedded in the road surface or as video cameras installed in strategic locations to monitor traffic entering and passing through intersections (*17*). These detectors allow vehicles to be tracked through an intersection from point of ingress to point of egress. To account for privacy, vehicles are not tracked individually but rather as a statistical entity.

Wireless Sensor Networks

WSNs collect data through transceivers, sensors, machine controllers, microcontrollers, and user interfaces with at least two nodes communicating by wireless ways. Not only does this technology use a wireless network for data transmission, it also collects data through the various forms of technology listed above. For this reason, WSN is discussed as both a data collection and data transmission technology (*6*, *18*).

Biometrics

Biometrics is an identity verification technology that uses anatomical features to achieve individual authentication. Common types of biometric technology include fingerprint scanner, face recognition, DNA, retina identification, and handprint structure. These technologies are useful in SCM because these identification technologies could measure registration times, for example, when someone enters or exits a building (*19*, *20*). In terms of freight data, biometrics can provide data to “reduce overhead by warning of excessive fuel consumption, identifying billing anomalies, reducing overtime expenses, and easily detect any unauthorized use of a vehicle” (*21*). For instance, one of the first uses of biometrics in the transportation industry took place in 1999 at the Rotterdam seaport. This port used hand recognition as an access authorization system for truck drivers entering the terminal (*22*).

Table C-3 shows the similarities and differences between each data collection technology.

Table C-3. Data Collection Technology Comparison.

Specification	RFID	Optical Codes	Inductive Technology	WIM Systems	Video Vehicle Identification	WSN	Biometrics
Range	1 mm to 100 ft	Next to barcode scanner	4–40 m	10–80 mph	Usually up to four lanes	>100 m	>1 m
Accuracy	99.97%	Varies based on human error	—	96%	—	Accurate within 1.2–2.2 m	Many different outlying factors can affect the accuracy of biometrics
Reading Rate	100–200/ second	4.5 m/s	20 Hz in ac, or 500 Hz to 5 kHz in dc	—	—	—	3000–6000 units per minute
Error Rate	-10^4	1 in 394,000	2% or less	±5%	—	—	0.0001–0.0009
Cost	Medium	Low	Low–High	High	Medium–High	Medium	High
Frequency Used	125–134 KHz	—	IEEE 802.15.4	—	Can use high frequencies	315 MHz, 433 MHz, 868 MHz (Europe), 915 MHz (North America), and the 2.45-GHz Industrial-Scientific-Medical (ISM)	HID Standard 26 bit, HID Full 26 bit, HID 34 bit, Mifare 32 bit, and EM

Source: Institute of Electrical and Electronics Engineers (IEEE).

Data Transmission Technologies

Data transmitting technologies are those that send data through a network or other electronic device for different purposes. These technologies allow communication between point-to-point, point-to-multipoint, and/or multipoint-to-multipoint systems or objects. The importance of this type of technology is that raw data collected need to be transmitted for processing in order to be useful for modeling and other types of analyses. This subsection describes technologies in charge of transmitting data.

Bluetooth

Bluetooth is a wireless standard that transmits data over short distances, usually up to 10 m (33 ft). Mobile equipment or RFID tags can be used to transmit the data. This technology was designed to replace data cables. Bluetooth application is ideal for internal conditions, such as warehouses, which are ideal for short-range communication (*6*).

Global Positioning System

GPS works through signals that satellites send to Earth and that are detected by mobile or stationary receiving devices. These signals are used to determine the receiver's position in the planet surface with an average accuracy of millimeters through a triangulation system called oversimplification.

While GPS is not ideal for internal warehouse tracking because of lack of accuracy and satellite signal, it is the best practice used for fleet tracking and management. GPS is an advantageous technology and can complement many other technologies when used concurrently. GPS is mostly used in transit operations but can also be used in asset tracking (*10, 23, 24*).

Wireless Sensor Networks

WSNs are networks of transceivers, sensors, machine controllers, microcontrollers, and user interfaces with at least two nodes communicating wirelessly.

Advantages of using WSN include:

- Avoid wiring through wireless technology.
- Updates and innovative technologies can be implemented without human interaction.
- Can cover a large reading range area (*6*, *18*).

Wi-Fi Real-Time Location System

Wi-Fi RTLS is a derivation of WSNs. This technology is essentially a tracking system based in Wi-Fi 802.11(x), whose main objective is to locate objects within its network coverage. RTLS measures key performance indicators (KPIs) through tracking any important assets, such as PDAs, laptops, mobile phones, or scanners, without needing a tag. This technology has an advantage over satellite technology, such as GPS, in closed spaces like warehouses, where it is often difficult for satellite or cellular technology to receive a signal.

RTLS use Wi-Fi capabilities to ensure accuracy in locating objects. Often, these RTLSs will use active RFID tags for locating purposes. This type of technology integrates well with information and communications technology (*6, 25, 26*).

Machine-to-Machine

M2M technology allows for seamless communication between objects that do not necessarily require human involvement within the communication process. Data are transmitted over signals or radio frequencies without human interaction (*10, 27*).

Global System for Mobile Communication

GSM is a cellular-based system that started in Europe but has spread across the globe. This technology transfers data from mobile equipment such as a cell phone over the GSM network through a frequency of either 900 MHz or 1800 MHz. This technology started as 1G but was soon replaced with 2G and 3G technology (*25*).

General Packet Radio Service

GPRS is an extension (upgrade) of GSM technology. It uses 2G, 3G, or LTE cellular communication to transfer data. This system can transmit data through point-to-point or point-to-multipoint data connections. This type of technology can be integrated into the supply chain as a monitoring system, gathering real-time information using the various types of data collection technologies (*28*).

4G LTE

4G technology is the fourth generation of mobile phone cellular network communication technology. It follows the 3G standard. Since its release, a more advanced form of 4G technology, LTE, has been issued. LTE is a form of 4G technology, and the two are regularly categorized together as 4G LTE technology. This wireless communication technology powers today's mobile phones, IP technology, gaming devices and services, high-definition television, and cloud computing. This technology has become so integrated in our society that people use this technology multiple times a day.

Microwaves

Microwaves transmit data through radio frequencies. These waves are used for point-to-point short-range communication. The high frequency waves can send voice, video, or data information. Microwave technology uses small antennas to transmit data over the high frequencies. This technology can be implemented in SCM for transmission of voice identification, video vehicle detection, or raw data. Many other forms of transmission technology use microwaves in other standards, such as Bluetooth and Wi-Fi (*29*).

Table C-4 shows a comparison of the data transmission technologies, illustrating the similarities and differences between each type.

Table C-4. Data Transmission Technology Comparison.

	Bluetooth Technology	RTLS	GPS	WSN	M2M	GPRS	GSM	4G LTE	Microwaves
Specification									
Range	>10 m	1–10 m	10–15 m	Up to 100 m	—	26,000 m	26,000 m	26,000 m	1 mm–1 m
Cost	Medium	High	High	Medium–High	High	Medium	Low–Medium	Medium–High	Low
Frequency	2.4–2.485 GHz	Can use low frequencies	1.57542 GHz (L1 signal) and 1.2276 GHz (L2 signal)	1.57542 GHz (L1 signal) and 1.2276 GHz (L2 signal)	1.57542 GHz (L1 signal) and 1.2276 GHz (L2 signal)	1.57542 GHz (L1 signal) and 1.2276 GHz (L2 signal)	900 MHz or 1800 MHz	1850 MHz–3800 MHz	300 MHz and 300 GHz
Transmission Standard	ISM bands	ISO/IEC 24730-1	SPS (Standard Positioning Service)	IEEE 802.15.4	—	3G, LTE	1G, 2G, EDGE	4G, LTE	SHF (3–30 GHz) or IEEE
Data Type									
Automated System		✓	✓	✓	✓	✓	✓	✓	
Communication between Devices	✓	✓	✓	✓	✓	✓	✓	✓	✓
Multiple Sensor Points		✓	✓	✓	✓	✓	✓	✓	✓
Satellite and/or Cellular Based			✓	✓*	✓	✓	✓	✓	

*Not limited to satellite based; can be used through other local networks.

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APPENDIX D: DATA PROCESSING TECHNOLOGIES

DATA PROCESSING TECHNOLOGIES

Data processing technologies refine, classify, and organize the collected and transmitted data in a way that is easier to understand. These technologies are software packages that help improve efficiency and communication within the supply chain. Many of these technologies are supply chain oriented. Their importance resides in the fact that several of the supply chain activities are freight generators. For instance, inventory changes location and management as it runs down the supply chain. This inventory movement depends greatly on transportation. Data processing technologies help in assessing current conditions of the supply chain, sharing databases, and tracking inventory. Good examples of data processing technologies relevant to transportation are the TMSs, which generally process data collected via GPS, RFID, GSM, or other outdoor tracking technologies to provide information on transport conditions such as vehicle locations and corresponding routes to develop delivery/pickup or load/unload schedules.

Advance Planning and Scheduling

APS is a type of software system that supports solving primarily operative planning problems in SCM, logistics, and operations management with the help of quantitative solution methods (operation research methods). According to the American Production and Inventory Control Society, APS have five main functions:

1. Demand planning.
2. Production planning.
3. Production scheduling.
4. Distribution planning.
5. Transportation planning (*1*, *2*, *3*).

Enterprise Resource Planning

ERP provides multiple application modules to support business management in departments such as finances, sales, supply, inventory management, quality management, product design, logistics, manufacturing, human resources, and operations spread out over the supply chain. ERP can measure KPIs through software and organization business processes. The aim is to achieve the link between providers and end users throughout the supply chain (*1*, *2*, *4*, *5*, *6*, *7*, *8*).

Warehouse Management System

WMS manages the movement and storage of materials within a warehouse, not only physically but through transactions, shipments, reception, location, and order consolidation. WMS can be used as a stand-alone system or can be a function of an ERP, APS, or CTM (*6*, *9*).

Transport Management Systems

TMS is the system responsible for shipment programming, vehicle transport management, modeling and benchmarking or transport operations, maintenance databases, delivery note and invoice generation, cargo optimization and planning, carrier and mode of transport selection, loss or damage complaint processing, and documentation management. TMS can be used as a stand-alone system or can be a function of an ERP, APS, or CTM (*6*).

Collaborative Transport Management

CTM involves converting order forecasts developed via collaborative planning, forecasting, and replenishment into shipment forecasts and collaboratively ensuring accurate fulfillment (*10*). CTM focuses on enhancing communication for the three main parties within the supply chain:

- Shipper.
- Carrier.
- Receiver (*6, 10*, *11*, *12*, *13*).

Data processing software packages often overlap in their application and functions in the supply chain. Often, multiple software packages are used simultaneously. For example, an advanced planning and scheduling system might pull data from a WMS or a TMS to use in future projections.

CONCLUSIONS

Table D-1 provides a clear picture of the software functions, displaying their individual strengths. The three types of technologies—data collection, transmission, and processing—interact with each other to provide usable information and datasets. They also provide data or information pertaining to the four basic data elements or primary indicators presented in the freight metrics section: time, distance/OD, volume/value, and cost. Understanding technologies' capabilities in terms of what data elements they can measure is necessary to realize their use in modeling.

Table D-1. Data Processing Technology Comparison.

	APS	WMS	TMS	ERP	CTM
Forecasting					
Demand Forecasting	✓				✓
Transportation Planning	✓		✓	✓	✓
Distribution Planning	✓	✓		✓	✓
Short-Term Planning	✓	✓	✓	✓	✓
Long-Term Planning	✓				✓
Monitoring					
Procurement				✓	✓
Real-Time Updates	✓		✓		
Interdepartmental				✓	✓
Scheduling	✓	✓	✓		
Assessment					
Improves Efficiency throughout the Entire Supply Chain	✓	✓	✓	✓	✓
Proactive System	✓				✓
Reactive System		✓	✓	✓	
Warehouse Assessment		✓			
Route Management			✓		
Interorganizational	✓	✓	✓	✓	
Intraorganizational					✓
Assesses Multiple Parties in SCM	✓			✓	✓

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APPENDIX E: TEXAS MPO FREIGHT PLANNING ACTIVITIES LITERATURE REVIEW

INTRODUCTION

This appendix summarizes the activities undertaken in Project 0-7037 to understand the ongoing work of Texas MPOs regarding freight planning. These findings reflect the activities at the time this review was completed early in the project during fiscal year 2021. Additional freight planning activities may have taken place since the time of this review.

SPECIFIC MPO DISCUSSIONS

The large MPOs in Texas are very active with freight planning and modeling and produce numerous documents detailing freight issues in their regions and the planning activities underway to address them. To better understand the regional issues and tools utilized by the small and mid-sized MPOs, the research team reached out to a select number for direct conversations. Three representative MPOs were chosen for interviews under this task added by the 0-7037 project panel because of the specific freight challenges in their regions:

- El Paso—Border MPO with freight planning activities.
- Permian Basin—Oil and gas activity, along with interstate highway and a high amount of through-freight movements.
- Waco—Interstate through-freight movements and location along one of the Texas Triangle corridors.

El Paso MPO

The research team discussed freight planning issues and activities with Salvador Gonzalez, transportation research and development manager, on February 24, 2021.

Travel Demand Model

El Paso has a travel demand model that considers three sizes of trucks. It relies on the Texas SAM model for external data. The MPO is concerned about characteristics of drayage movements, such as trip length, because the data for that part of its model are considered outdated.

International Movements

Gonzalez expressed a need for more disaggregated data than what the U.S. Department of Homeland Security CBP currently provides, noting that it would be helpful to have OD data, wait times, and times of day. Gonzalez felt like the MPO had a good handle on the cross-border movements, but then recently, CBP altered staffing, which dramatically slowed cross-border freight movements.

Railroad

At the time of the interview, Gonzalez stated that the MPO does not do much with rail because it does not have many planning requirements for that mode. They feel that the lack of understanding of rail activity in the region is another weak link that could be addressed. Their understanding is that the new border master plan will examine rail in-depth. The MPO gets rail projects to include, such as grade crossings and grade separations, from the city, the county, TxDOT, and the railroads. The MPO's TDM does capture truck trips to rail intermodal yards, which are treated as a basic economic generator, similar to warehouses.

Tools

Gonzalez stated that the MPO often uses TTI-developed tools, especially COMPAT, for emissions monitoring, congestion monitoring, and project selection. They would welcome another tool that could help them.

Staffing

The MPO has good staff capable of running its TDM model but would "always like two additional staff members" to assist if personnel and resources were made available.

Permian Basin MPO (PBMPO)

The research team discussed Permian Basin region freight issues and planning activities with Ken Van Dyne, senior transportation planner, on March 2, 2021.

Travel Demand Model

PBMPO recently acquired the TxDOT TDM TexPACK application (online app) as a TDM tool. Van Dyne did not believe their modeling calls out truck movements specifically.

Data Needs

The problems in the Permian Basin MPO are not static since regional oil and gas activity is volatile and mobile in nature. The MPO showed interest in understanding the availability of any new real-time data sources that would allow staff to better understand patterns and outreach to inform stakeholders of current conditions. Having a better idea of current and upcoming drilling activity would also benefit planning activities. It would be beneficial to have axle weight information to be better informed on locations of heavy truck movements.

Staffing

Van Dyne had been at the MPO for less than two months at the time of the interview, taking a planning position that had been vacant for over eight months. Before his arrival, only the director and support staff positions were filled, leaving three vacant at the time of the interview

Waco MPO

Discussions with Chris Evilia, Waco MPO director, regarding freight issues and planning activities through the Waco region occurred on March 3, 2021.

Region Freight Activity and Concerns

The two major freight activities in the Waco MPO region are freight movements that pass through the region and freight movements to a major industrial park, known as the Texas Central Park. As the "crossroads of Texas," I-35 is the major corridor through the Waco region; however, there are also a significant amount of truck movements along SH 6, traveling southeast to northwest to Abilene, and SH 31, traveling northeast to Tyler/Longview. In many instances it is believed that these non-I-35 routes are chosen to bypass the Dallas–Fort Worth urban highway network, especially for movements of oversize/overweight (OS/OW) permitted loads, including windmill components headed toward Abilene and western Texas. OS/OW and other truck movements are not overly impacted by infrastructure deficiencies in the Waco MPO, such as bridge heights, since the recent reconstruction of I-35 through the region has greatly improved vertical clearances in the area.

Texas Central Park and surrounding areas are expected to account for nearly 40 percent of the region's employment in the future. Texas Central Park is located at the juncture of I-35, US 84, and SH 6, providing it with good truck access. The park also has rail access, which is an asset; however, it has been relayed to the MPO that the host railroad seems to be slower to pick up and deliver rail cars recently. Train operations through the region tend to move along without major delays, but the rail traffic trend seems to be toward longer trains that are adding to delay at crossings, particularly in close proximity to the industrial park. Grade crossing safety is also a concern in downtown Waco near prominent tourist attractions.

The area around the city of McGregor to the west of Waco is also developing an industrial complex at the former Naval Reserve Ordnance Plant, where Space-X is currently performing rocket testing. Waco MPO noted that the Space-X activity has attracted a few supporting industry companies. A major concern for transportation planners at the MPO and TxDOT is addressing increased truck activity through downtown McGregor due to the lack of alternative routes.

Staffing

Waco MPO had three staff members at the time of the interview, including the director. With the possibility of becoming a transportation management area due to increased population in the U.S. Census, they were actively examining future staffing needs.

Freight Planning Activities and Tools

Evilia noted that the Waco MPO travel demand model does not currently consider truck flows; however, they expect the next iteration to include that capability. They are utilizing the TTI-developed COMPAT tool, which assists in identifying the highest truck volume routes and performing analyses, such as high truck flow corridors against travel speeds. The MPO's travel time reliability and truck reliability planning efforts are currently rudimentary.

Having more detailed data to better understand what freight is moving through and within the region is desired by Waco MPO. Current data are largely at the county level. It was unclear whether commodity-specific data would be critical; however, the MPO's experience is that having more and better data greatly improves clarity.

With the MPO's current staffing levels and capabilities, it generally needs more simple, easy-to-learn tools to accomplish planning activities. The MPO is willing to act as a test area for the tool developed for this project.

MPO FREIGHT PLANNING DOCUMENT REVIEW

This section documents the scan of other Texas MPO freight planning activities via review of their planning documents rather than a direct interview.

Abilene MPO

Abilene MPO 2045 Metropolitan Transportation Plan

Abilene is located along major national and statewide freight corridors, including I-20, US 83, and US 84, as shown in Figure E-1. Windstar Industrial Center is in northeastern Abilene, Five Points Business Park is in western Abilene, and Access Business Park is in southeastern Abilene. The metropolitan transportation plan (MTP) indicated that managing freight activities in those industrial centers, especially along I-20 and SH 36, will be critical. However, the Abilene MPO and surrounding areas do not currently have a specific freight plan.

Abilene is reported to have a significant amount of truck and rail tons that travel through the region each year. The MPO expects that widening I-20 will provide enhanced freight movement through the city and region. It is recommended that future MTPs consider developing a freight mobility plan to investigate the infrastructure and economic context of the area in terms of freight movement.

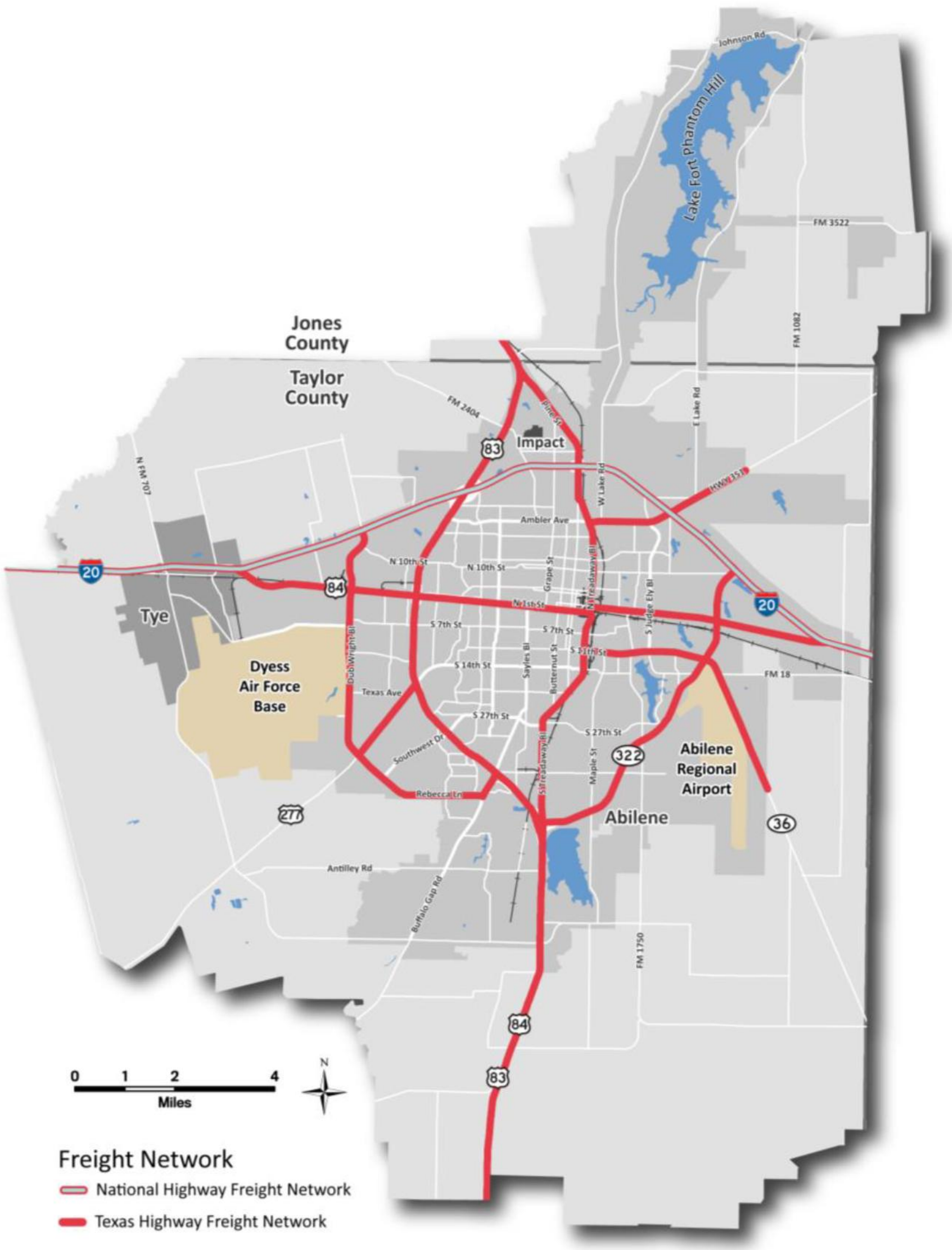


Figure E-1. Freight Network in Abilene MPO Region.

Amarillo MPO

Amarillo Metropolitan Transportation Plan 2020–2045

Amarillo is located at the crossroads of I-40 and I-27. I-40 is a major corridor for nationwide freight distribution that runs from Wilmington, NC, to Barstow, CA. I-27 connects Lubbock with Amarillo. The corridor also parallels the BNSF's Plainview Subdivision and US 87, and it is part of the Ports-to-Plains Trade Corridor. This corridor runs from the Mexican border to Denver, CO, via I-27, which is one of four congressional high-priority corridors.

Amarillo MPO is facing the following freight issues identified in the MTP:

- Freight movement that has long distances traveled could cause local problems without local benefits.
- Improvements targeting general traffic are not likely to aid some aspects of the flow of freight.
- The addition or loss of a single major business could dramatically change the level of freight activities.
- Since freight movement is extremely diverse, solutions aimed at average travel conditions are less likely to work for freight.
- The growing needs of freight transportation cause conflict between interstate and local interests.
- Freight movement places a heavy burden on infrastructure.

One of the MPO's intelligent transportation system (ITS) projects is aimed at promoting signalized intersections to eliminate congestion and improve truck freight mobility, which is part of planned MTP projects. The MPO is also seeking to develop a multimodal transportation plan.

Bryan/College Station MPO

Destinations 2045: The Bryan/College Station MPO Metropolitan Transportation Plan

In the Bryan/College Station area, the two major freight traffic sources are the Union Pacific (UP) railroad and truck shipments. The two primary corridors used by motor carriers are SH 6 and SH 21. There are nine motor freight carriers in the area, and they have up to 100 tractor-trailers in a combined operation. The annual freight growth rate of the MPO is 0.34, while the average annual freight growth rate of all Texas MPOs is 0.44.

It is reported in the MTP that actual motor freight traffic within the area is hard to verify due to the lack of specific research on the topic. Currently, the Highway 36A Coalition is seeking to construct a new rail line from Port Freeport to Rosenberg to connect to the existing UP and BNSF tracks. The existing SH 36 would be widened from Port Freeport to Rosenberg, and then new sections of roadway would connect to SH 6 in the Hempstead area. This conceptual route would allow truck traffic to both avoid downtown Houston and bypass accessing downtown Fort Worth via I-35W or Dallas via I-35E if a route west of Fort Worth could be identified. Bryan/College Station MPO has included a subtask in its Unified Planning Work Program to address how much additional traffic would be added through Bryan/College Station by a rail or truck route of this sort.

Capital Area Metropolitan Planning Organization (CAMPO)

2045 Regional Transportation Plan

CAMPO and the TxDOT Austin District are working toward improvements to the connections of I-35, I-10, US 290, US 183, SH 123, and SH 71. Among the corridors, I-35 is one of the most heavily traveled and congested corridors in the state. The plan indicated that further study is needed on the interconnectivity of freight movements in the area, including growing areas for warehousing and distribution centers. Other freight activities include:

- TxDOT and CAMPO are partnering to improve incident management in the region that is aiming to limit traffic disruptions caused by accidents and incidents on the roadways.
- Plans are working to improve the ITS infrastructure to provide drivers better roadway information.
- In the future, the Capital Express Project is expected to add non-tolled managed lanes on both directions of I-35.

Corpus Christi MPO

2020–2045 Metropolitan Transportation Plan

Corpus Christi MPO identified the THFN on its regional roadway system and available truck stop locations with associated amenities. Figure E-2 shows that several sections of the MPO freight network are highly congested.

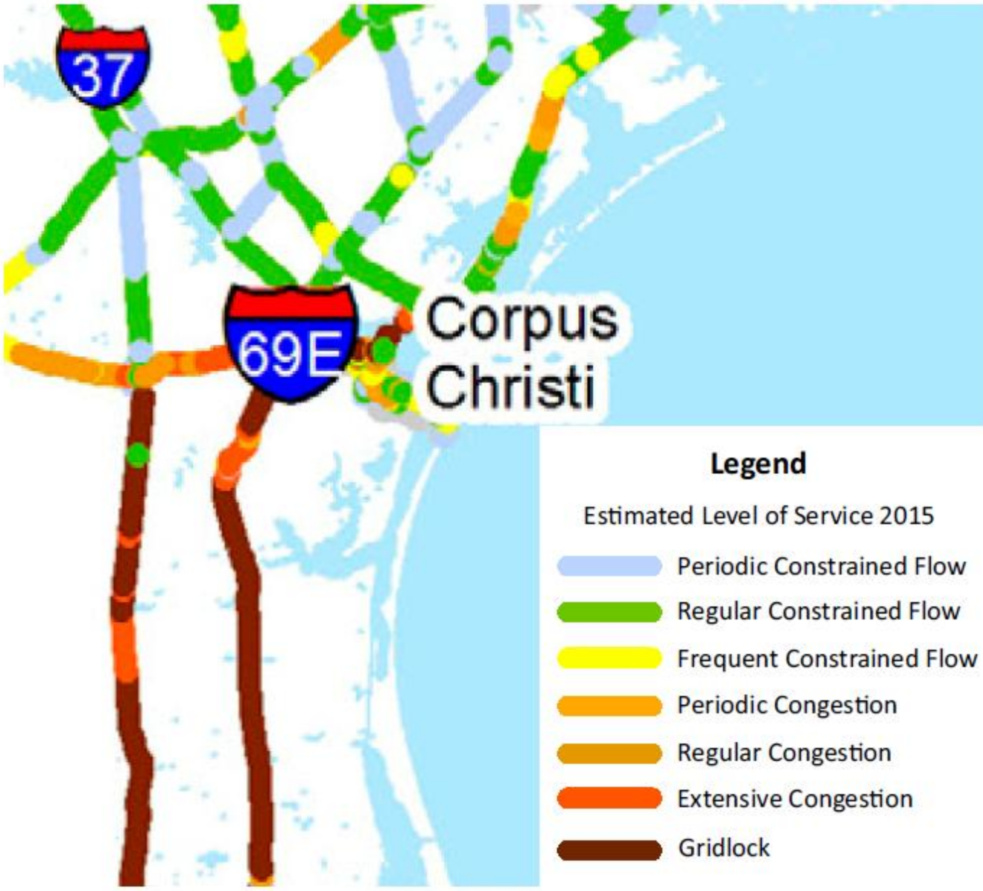


Figure E-2. Map of Corpus Christi Region's Freight Congestion.

The volume of commodities accommodated by the Port of Corpus Christi Authority (PCCA) continues to grow. The port set a new tonnage record of 106,237,407 short tons in 2018. The leading commodity is petroleum products. PCCA has invested in capital projects and operational improvements to address the issue.

Following is a list of reports about freight sponsored by TxDOT and Corpus Christi MPO:

- *Major Freight Facilities Impact Study: Final Report* (February 2010).
- *A Regional Freight Study of the Corpus Christi and Yoakum Districts* (May 2010).
- *Hazardous Materials/Truck Traffic Study: Corpus Christi, Texas* (September 2016).

El Paso MPO

DESTINO 2045 Metropolitan Transportation Plan—Needs Assessment Report

The El Paso region is a critical transfer point for commodities at the U.S. and Mexico border. The MPO performed a freight network congestion analysis by using peak-period congestion measures produced from the 2045 El Paso travel demand model. The study concept, shown in

Figure E-3, expected that approximately 34 percent of the delay on the freight network would occur on I-10.

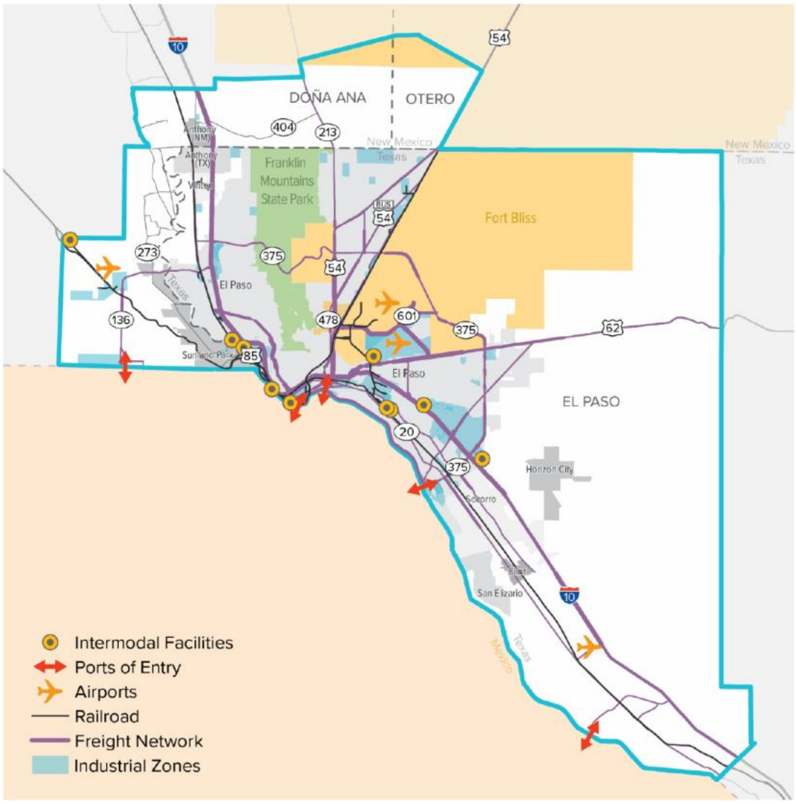


Figure E-3. Intermodal Facilities and Ports of Entry in the El Paso Region.

Based on a comparison of vehicle hours of delay between 2012 and 2045, Loop 375 is expected to have the most significant increase in vehicle hours of delay, but I-10 will still experience 3 million more vehicle hours of delay compared to Loop 375 in 2045. The congestion is also expected along freight corridors near El Paso International Airport and the southwestern portion of Fort Bliss, where major freight terminals and intermodal transfer facilities are located.

Houston-Galveston Area Council (H-GAC)

2045 Regional Transportation Plan

More than 465 million tons of goods are shipped annually over the Houston-Galveston region by commercial truck freight. By 2045, it is expected that commercial trucks will transport 54 percent of all freight shipments by weight.

The biggest challenge that H-GAC has is congestion since the ports are large freight generators. The freight corridors leading to and from ports need to have enough capacity to accommodate the level of freight generated. The increased freight demand caused by a growing economy could deteriorate bottlenecks and excessive delay.

Port Area Mobility Study

I-10, I-45, I-69, and I-610, as well as SH 36, SH 225, and SH 146, provide crucial connections to the Houston region's ports. ATRI reported that seven out of the top 100 truck bottleneck locations in the United States are in the H-GAC region. As shown in Figure E-4, H-GAC's travel demand model suggested a significant increase in truck volumes along I-610 on the east side of downtown, I-10E east of the Sam Houston Tollway, and SH 225 between I-610 and the Sam Houston Tollway.

Following are the projects aimed at port-related mobility that have been identified by H-GAC, TxDOT, Harris County, and Port of Houston:

- The expansions of I-45 (from NASA Road 1 to FM 1764 in Texas City) and SH 146 (from Red Bluff Road to FM 517) are expected to aid the truck movement to and from Ports of Galveston and Texas City
- The upgrade project of a 55-mile stretch of SH 36 from the Port of Freeport to I-69 at Rosenberg includes adding a grade-separated crossing with SH 35 and widening lanes from two lanes to four lanes.

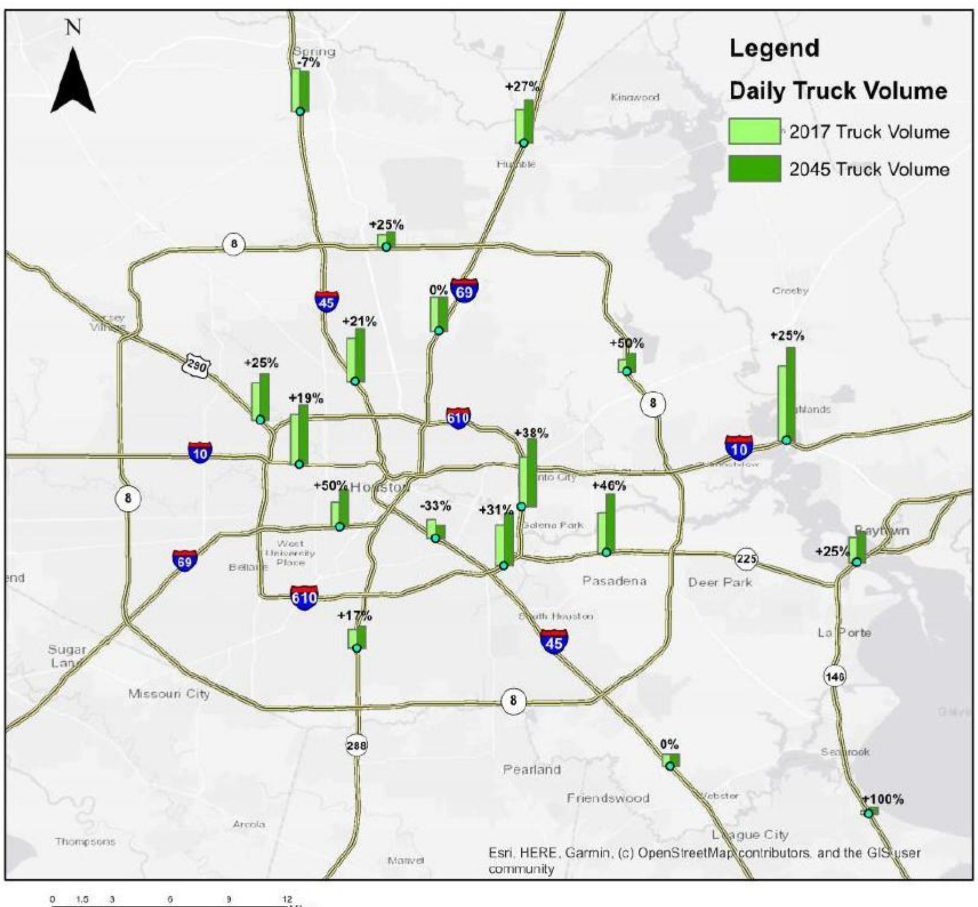


Figure E-4. Truck Volume Comparison between 2017 and 2045.

Killeen-Temple MPO (KTMPO)

Mobility 2045 Metropolitan Transportation Plan

The MTP includes a list of truck routes identified by the KTMPO Freight Advisory Committee, as shown in Table E-1. US 190/I-14 is a major east-west freight corridor in the area, along with I-35 that traverses the area north-south. The Civilian-Military Joint Use Rail-Truck Multimodal Facility is under consideration for a site on Fort Hood, located between the railroad tracks and I-14.

Table E-1. Truck Routes identified by the KTMPO Freight Advisory Committee.

Road	Limits From	Limits To
FM 93	I-35	US 190
FM 436	I-35	US 190
FM 439	SH 195	SH 317
FM 1741	US 190	FM 93
LP 121	FM 436	FM 439
SH 36	Coryell County Line	LP 363
SH 53	LP 363	Falls County Line
SH 317	FM 439	McLennan County Line
Temple Outer Loop	I-35 at Hart Rd	I-35 South of Temple

North Central Texas Council of Governments (NCTCOG)

NCTCOG Mobility 2045

In 2015, the area accounted for 30 percent of Texas' GDP. Four major interstate highways—I-20, I-30, I-45, and I-35—cross the region, and there are more than 600 commercial motor carriers and roughly 100 freight forwarders operating in the area.

The MTP suggested that the following freight transportation issues in the region must be considered in the freight planning process:

- First/last-mile connections.
- Inadequate infrastructure.
- Growing congestion on major regional transportation facilities.
- Truck parking.
- Safety.

Freight North Texas is an ongoing planning program led by NCTCOG. The guidance document, published in May 2013, is titled *The North Central Texas Regional Freight System Inventory*. Following is a list of the follow-up studies:

- Freight Congestion and Delay Study (published in March 2016).
- Regional Truck Parking Study (published in April 2018).
- Land Use Compatibility Analysis (in progress).
- Economic Impact of Freight on the Region (not yet started).
- Freight Project Evaluation System (not yet started).

Freight Congestion and Delay Report—A Freight North Texas Study

This study performed a congestion and delay analysis based on four focus areas:

- Alliance focus area.
    - Bounded by SH 114, SH 170, Alliance Airport, and the BNSF rail line.
    - Truck route continuity and railroad crossing delays were the main issues.
- Great Southwest focus area.
    - Bounded by SH 183, President George Bush Turnpike, SH 303, and SH 360.
    - Lack of sufficient turning radii at intersections and railroad crossing improvements were the primary concerns.
- International Inland Port of Dallas focus area.
    - Bounded by I-45, I-20, SH 342, and the Dallas/Ellis County Line.
    - Reconstruction of the interchanges near the intermodal facility and intersection improvements along the truck routes were identified as significant issues.
- Mesquite focus area.
    - Bounded by I-30, US 80, and the UP Dallas Subdivision.
    - Insufficient turning radii at multiple intersections on the truck routes and upgrading rural routes to urban lanes were major concerns.

Figure E-5 from the report shows the large number of freight developments in the region.

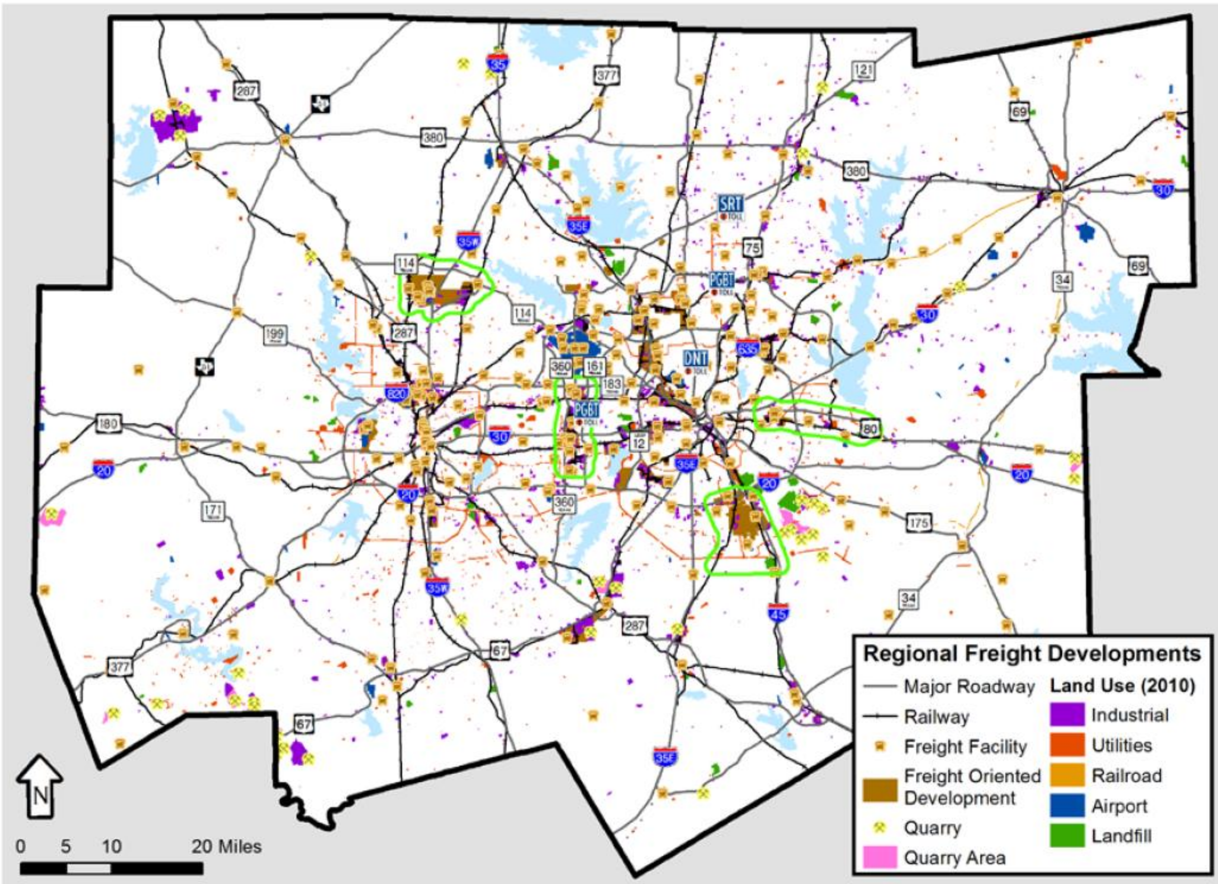


Figure E-5. Regional Freight Developments in the NCTCOG Region.

South East Texas Regional Planning Commission MPO (SETRPC MPO)

Jefferson-Orange-Hardin Regional Transportation Study (JOHRTS)

Key truck routes in the region, shown in Figure E-6, include I-10, US 69/96, and US 90. SH 73, SH 347, and SH 87 provide access to the Port of Port Arthur and landside linkages to the Sabine-Neches Waterway.

Figure E-6. Freight Percentage of AADT in the SETRPC Area.

The MTP used IHS Market Transearch to assess trucking and freight rail demand, the FHWA FAF to assess pipeline and air cargo demands, and the U.S. Army Corps of Engineers (USACE) Waterborne Commerce Statistics to determine the port and waterway demand. In 2015, approximately 116 million tons of goods were transported on the tri-county highway network. By 2045, truck freight in the area is projected to increase to over 222 million tons.

Laredo MPO

2020–2045 Laredo Metropolitan Transportation Plan

The recent United States–Mexico–Canada Agreement (USMCA) has resulted in increased demand for trucking, warehousing, and supporting industries in the region. The Port of Laredo also serves as a major connection for freight movement between the United States and Mexico. A regional freight master plan has not been developed but is a key priority for the MPO.

The Laredo region has designated truck routes to accommodate commercial freight trucks as follows:

- I-35.
- US 59 and US 83.
- SH 359, Loop 20, SH 255, and Spur 260.
- Other farm-to-market roads and arterials.

Based on the Laredo MPO travel demand model, the MPO expects significant congestion on many of its truck routes in the future. I-35 is going to be expanded to six lanes. However, some segments are still expected to be congested with level-of-service (LOS) F traffic, as shown in Figure E-7. The combined segment of SH 359/US 83 between US 83 and I-35 is expected to increase congestion to unacceptable levels of service by the year 2045.

Major truck facilities within the region are mainly on the north side of Laredo, along Mines Road. The International Commerce Center and Las Minas Industrial Park are adjacent to the Laredo Columbia Solidarity Bridge. La Barranca Industrial Park, Flying J, and Travel Centers of America are located along the north side of I-35.

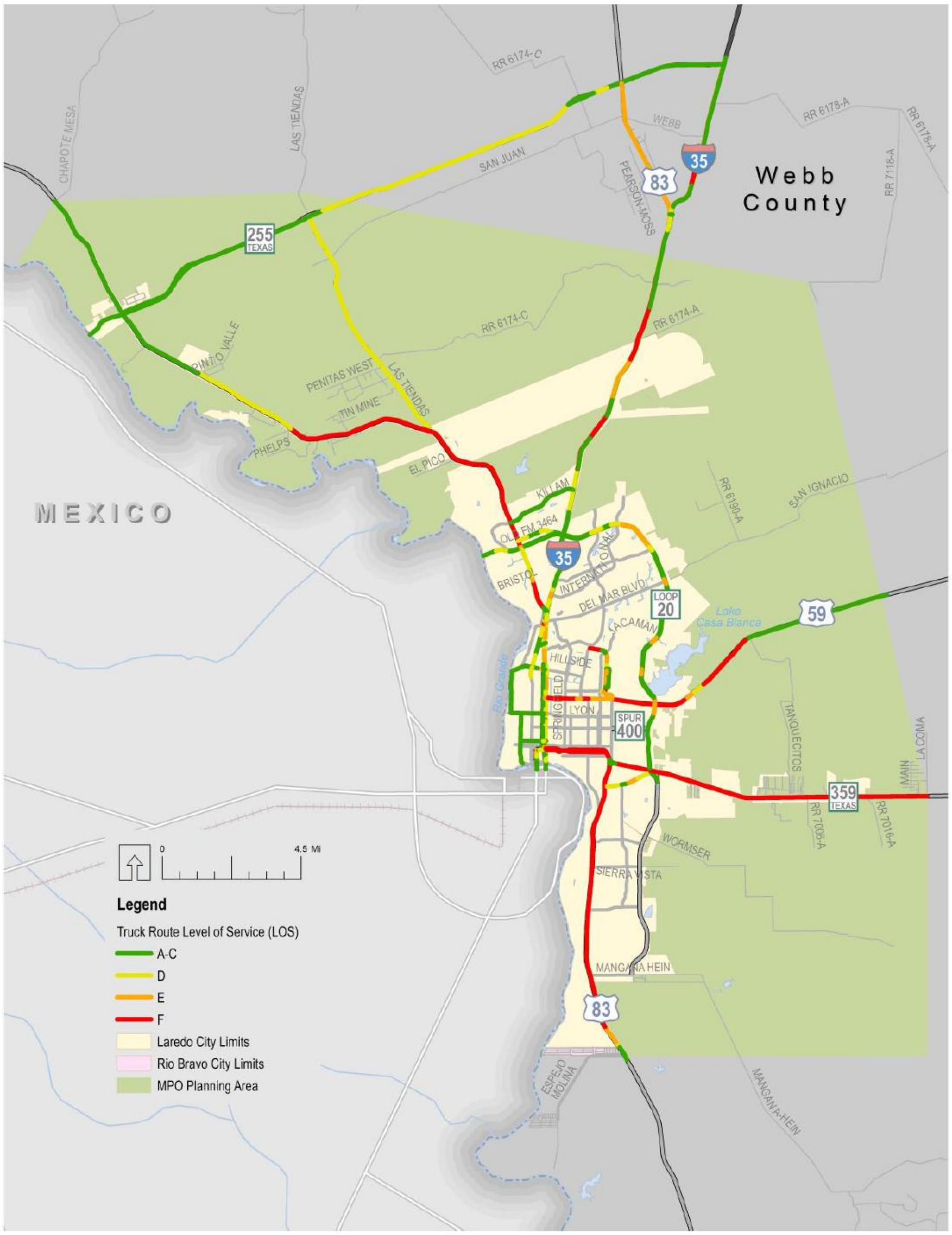


Figure E-7. Forecast Truck Route LOS in 2045.

The combined freight tonnage in the Laredo border district is expected to double over current conditions by 2045. The MTP underscored that the demand growth demonstrates the need to plan and develop road, rail, and border crossing infrastructure.

System capacity issues are one of the significant challenges to Laredo. Some problems and recommendations were identified in the public outreach and focus group meetings:

- Land use barriers have an impact on the lack of new freight facilities.
- ITS solutions should be considered for efficient freight movement.

- A lack of direct connections to I-35 need to be addressed.
- More funding is needed to improve I-69/US 59.
- I-69 in connection with Loop 20 and I-35 needs to be examined. Adding more lanes on I-35 to San Antonio would increase truck traffic throughput.
- Peak-hour congestion lasts until about 6 p.m. due to travel to and from Mexico.
- Laredo's international bridges are experiencing high levels of congestion.
- Since there is room to widen the bridge, increasing the capacity of the Columbia Bridge could be a potential project.

Longview MPO

Mobility 2045—Metropolitan Transportation Plan

The key freight traffic corridors within the area include SH 31, US 271, US 259, SH 300, US 80, Loop 281, Spur 502, and Spur 63. The MTP identified needs as follows:

- Access to major intercity routes on I-20, US 271, US 259, and SH 31.
- Adequate thoroughfares and access to major industrial and commercial areas.
- Emphasis on reducing congestion along freight corridors.
- Adequate physical facilities to accommodate trucks, including pavement condition, turning radii, and acceleration/deceleration lanes.

Lubbock MPO

2012–2040 Metropolitan Transportation Plan

The Lubbock Economic Development Alliance owns and operates the Lubbock Business Park. The business park is located off I-27, approximately 1 mile south of Lubbock Preston Smith International Airport. The ports-to-plains case study released in April 2007 identified that the development of freight rail as an extension of the Permian Basin Railways line to transport the local cotton crop and ethanol would reduce truck traffic in the Lubbock metropolitan area.

Permian Basin MPO

Forward 45

Major improvement projects are planned on a segment of I-20, including a new interchange at Faudree Road, U-turns and ramp reconfigurations, and conversion to a one-way frontage road from FM 1936 to CR 407.

Permian Basin Regional Freight and Energy Sector Transportation Plan—Fact Sheet

Freight challenges in the Permian Basin are listed as follows:

- The Permian Basin annually generates about 1,200 loaded trucks per new well and about 350 full trucks for each existing well.
- State-level data sources are limited to capture the growing freight activity arising from the energy sector.
- Between 2010 and 2018, there was a 47 percent increase in the number of roadway crashes and a 64 percent increase in roadway fatalities.

Rio Grande Valley MPO

2045 Metropolitan Transportation Plan

Rio Grande Valley MPO was (at the time of this literature review in 2022) the recently consolidated MPO formed from the Harlingen–San Benito (HSB), Hidalgo County (HC), and Brownsville MPOs. The MPO region includes three main highways: I-2, I-69E, and US 281. Cameron County contains one of the largest foreign trade zones in the United States. The zone includes Valley International Airport and Harlingen Industrial Park. The Port of Harlingen is a major intermodal facility in the area because it allows for freight to be received or shipped out of the Lower Rio Grande Valley via the Arroyo Colorado to the Gulf of Mexico. UP freight and the Rio Valley Switching Company are also in the former HSB MPO's area. The HSB MPO freight analysis used a subset of the Texas Statewide Travel Demand Model.

Many cities in the Hidalgo County region have designated truck routes. A preferred county truck routes plan will be created based on the collected designated truck route data from several cities within the former HC MPO region.

In the former Brownsville MPO region, most truck traffic occurs in the eastern quadrant of the city of Brownsville, where many warehouses are located along with SH 48. New commercial and industrial development is expected to the east of the airport and south of the Port of Brownsville. The former Brownsville MPO supported developing SH 32 since it cuts travel time to and from the Port of Brownsville and provides a safer route for some cargoes by avoiding schools.

The East Loop will connect the Veteran's International Bridge with the Port of Brownsville. The new East Loop corridor will provide better international access from Mexico and serve as the new overweight truck corridor by sharing overweight truck traffic on SH 48. The Brownsville Navigation District and the Cameron County Regional Mobility Authority agreed to cooperate on developing the South Port Connector, which will connect the port to SH 4 and the East Loop.

It was reported that relocating truck traffic from the Gateway International Bridge and the B&M Bridge to Veteran's International Bridge solved many issues in downtown Brownsville. It has allowed the traffic to and from the port to occur entirely within Brownsville's southeast quadrant. TxDOT has plans to build a truck inspection station next to the Veterans International Bridge at Los Tomates.

San Angelo MPO

Moving People and Things—Through and Within San Angelo 2045

One of the strategies suggested in the San Angelo MPO plan is the development of a multimodal freight terminal or "rail port" on the north end of town close to a rail spur and the reliever route. The strategy will provide heavy trucks with a dedicated operation field isolated from automobile, bicycle, and pedestrian traffic.

Alamo Area MPO

Mobility 2045

The center of the Alamo Area MPO region is located at the intersection of I-10 and I-35. Nearly 100 million tons of freight were hauled on sections of I-35 north and south of Loop 410. Major freight routes are shown in Figure E-8.

The Texas Clear Lanes program funded two projects in the MPO region: Loop 410 improvements from US 90 to SH 151 and US 281 expansion from Stone Oak Parkway to the Bexar/Comal County line. Both projects were expected to be completed by the end of 2020.

The MPO identified the following freight focus areas for the next five years in the MTP:

- Continue attending meetings and events held by freight transportation providers and related manufacturing and warehousing stakeholders.
- Streamline existing lists of recommended and desired freight transportation improvements on the public freight web page.
- Annually track the truck travel time reliability index on the interstate per federal performance measure requirements and participate in monitoring other state-level performance measures, where possible.
- Work with transportation agency partners, the private sector, and existing Transearch and FAF4 data to develop a portrait of freight, and seek opportunities to partner with state and regional partners on a freight-specific plan for the region.

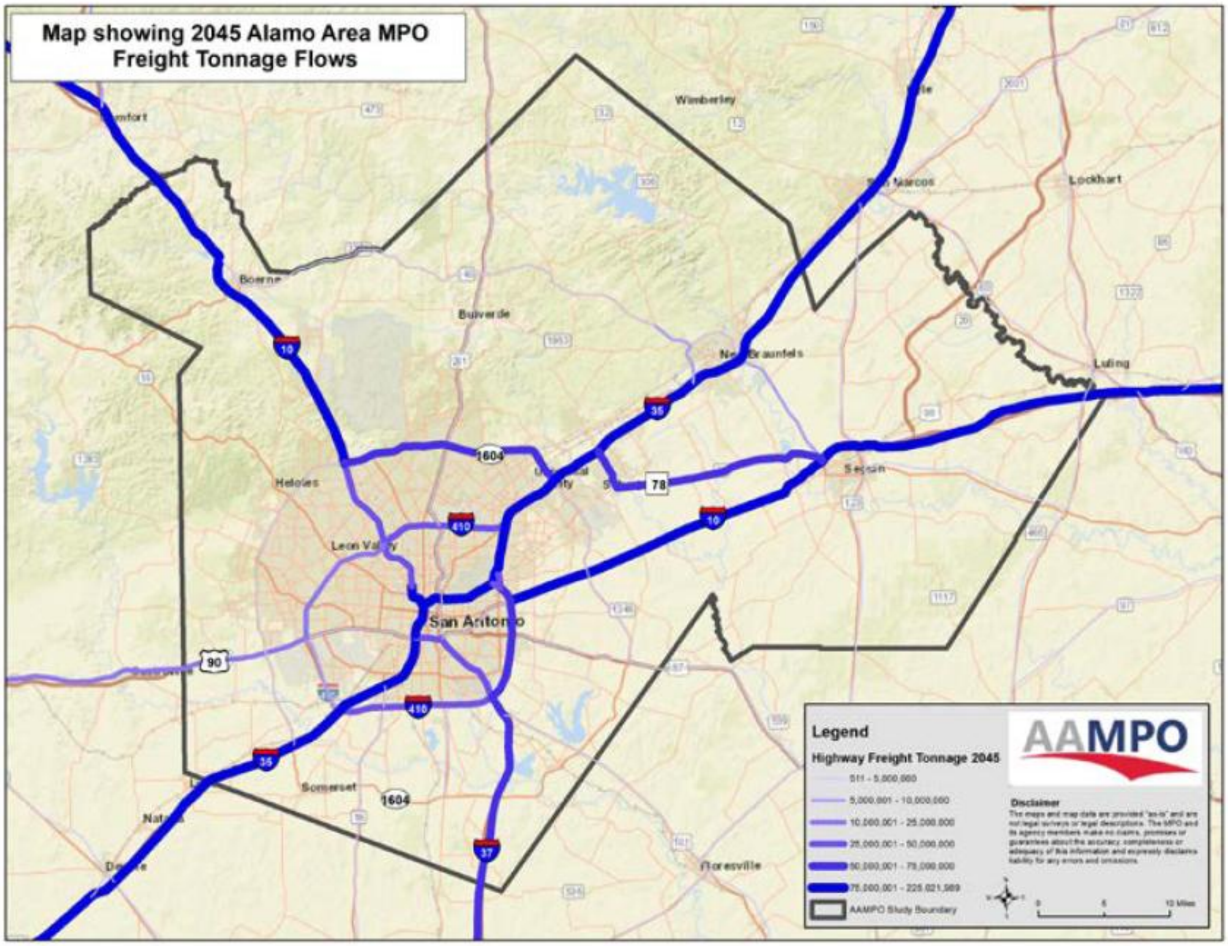


Figure E-8. Alamo Area MPO Freight Tonnage Flows in 2045.

Sherman-Denison MPO

Moving Forward: 2045 Metropolitan Transportation Plan and Grayson County Freight Mobility Plan

The Grayson County Freight Mobility Plan was released in September 2018. The study found that US 75 and SH 289 can be congested during peak hours, especially US 75, which has the highest average annual daily truck traffic with more than 6,500 combination trucks. However, most of the roadways within the county are not congested for freight. The county has two Class I railroads, BNSF and UP; two short-line railroads; and two airports, the North Texas Regional Airport and the Sherman Municipal Airport. Transportation-related solutions and economic development-related solutions that are identified in the plan are as follows:

- Transportation solutions.
  - Continue to engage freight stakeholders.
  - Reduce the impacts of oversize/overweight vehicles.
  - Pursue strategic land use and "smart growth."

    - Support infrastructure connections to other markets.
- Economic development recommendations.
    - Increase rail access and traffic.
    - Leverage the airport for growth.
    - Study manufacturing and logistics-based development opportunities.
    - Prioritize workforce development.

The pavement condition in the county is generally poorer than in Texas as a whole. Most of the freight-related issues are related to oversized loads and associated bridge clearance issues.

A freight-based strengths, weakness, opportunities, and threats (SWOT) analysis was conducted with the Grayson County Freight Advisory Committee on May 16, 2018. Table E-2 depicts the summary findings of the SWOT analysis.

Table E-2. Grayson County SWOT Analysis Findings.

Strengths	Weaknesses	Opportunities	Threats
US 75 connections to major markets	Outdated US 75 infrastructure	Booming population growth	Increasing US 75 traffic
Robust economic environment	OSOW vehicle challenges	Technological change	Changing workforce needs/technology
Available industrial sites	Underutilized rail and air facilities	Developing rail sites/yards	Supporting growing population
Workforce availability	Need for east-west highway connections	Airport-related economic development; relationships with other agencies (TxDOT, local ED)	Infrastructure obsolescence

Texarkana MPO

Texarkana 2045 Metropolitan Transportation Plan

In the MPO freight network, the areas, including I-30 from I-369 to US 71, US 59 just west of I-369, and the 7th Street/Texas Boulevard/New Boston Road area, are experiencing moderate-to-severe congestion. Additional congestion is expected as new intermodal facilities are built in the region. The Texarkana Freight Mobility Plan is still in progress.

Tyler Area MPO

Tyler Area 2045 Metropolitan Transportation Plan

There is high connectivity between the intermodal facility, the state freight network, and the Tyler Pounds Regional Airport through highways and major roads in the area. Figure E-9 illustrates freight routes and facilities in the region. The intermodal facility allows rail and truck transfer, and the Tyler Pounds Regional Airport now has air and truck transfer capabilities.

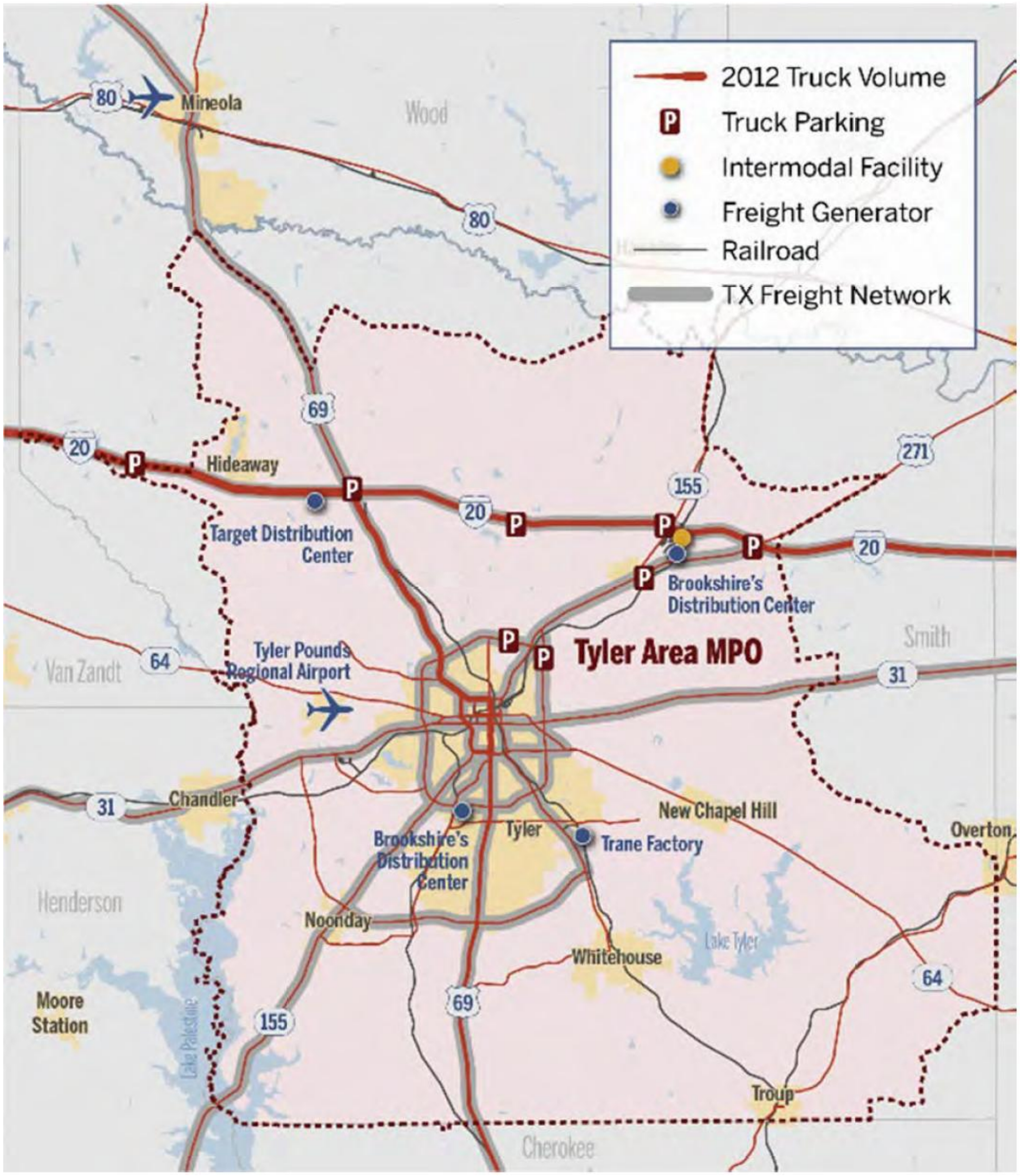


Figure E-9. Major Freight Generators of the Tyler Area MPO.

Victoria MPO

Victoria 2045 Metropolitan Transportation Plan

Freight generators in the area are generally concentrated near intermodal facilities such as the Victoria Regional Airport and Port of Victoria. US 77 near Loop 463 and US 59 in downtown Victoria are corridors with the highest levels of truck traffic.

The MTP identified six unreliable segments and their respective level of travel time reliability values by time period, as shown in Table E-3. Travel time data are provided as part of FHWA's NPMRDS.

Table E-3. Unreliable Freight Segments in the Victoria MPO Area.

Roadway (From–To)	Direction of Travel	6–10 AM	10 AM–4 PM	4–8 PM	Weekend 6 AM–8 PM
US 87N (S US 77 frontage–N US 77 frontage)	NB	1.51	1.58	1.61	1.55
US 87N (S US 77 frontage–N US 77 frontage)	SB	1.66	1.60	1.67	1.60
N Navarro St (S US 77 frontage–N US 77 frontage)	NB	1.67	1.54	1.58	1.64
N Navarro St (S US 77 frontage–N US 77 frontage)	SB	1.58	1.56	1.63	1.57
W Rio Grande St (S Zac Lentz Pkwy–N Zac Lentz Pkwy)	SB	1.71	1.71	1.71	1.57
E Rio Grande St (W North St–N Navarro St)	SB	1.46	1.56	1.55	1.47

Waco MPO

Connections 2045: The Waco Metropolitan Transportation Plan

A majority of state freight network facilities are state highways designed to accommodate heavy trucks. However, several local arterials were identified as unsuitable to accommodate heavy trucks. The MTP noted that highway access and roadway condition are not often a consideration when large freight generators are given site location approval. The plan also mentioned that infrastructure availability is often not considered when approving industrial or high-intensity commercial zoning and land use designations. The MTP suggested that member municipalities and McLennan County may need to reconsider street design for new subdivisions and reconstruction of existing streets to account for the increasing direct home delivery of retail goods.

Wichita Falls MPO

Wichita Falls MPO 2045 Metropolitan Transportation Plan

The major freight corridor with high levels of congestion is along FM 369 in the west between SH 277 and SH 287. SH 79 near Lakeside City and SH 277 near the FM 369 junction are expected to see increases in congestion by 2045. Figure E-10 illustrates those corridors.

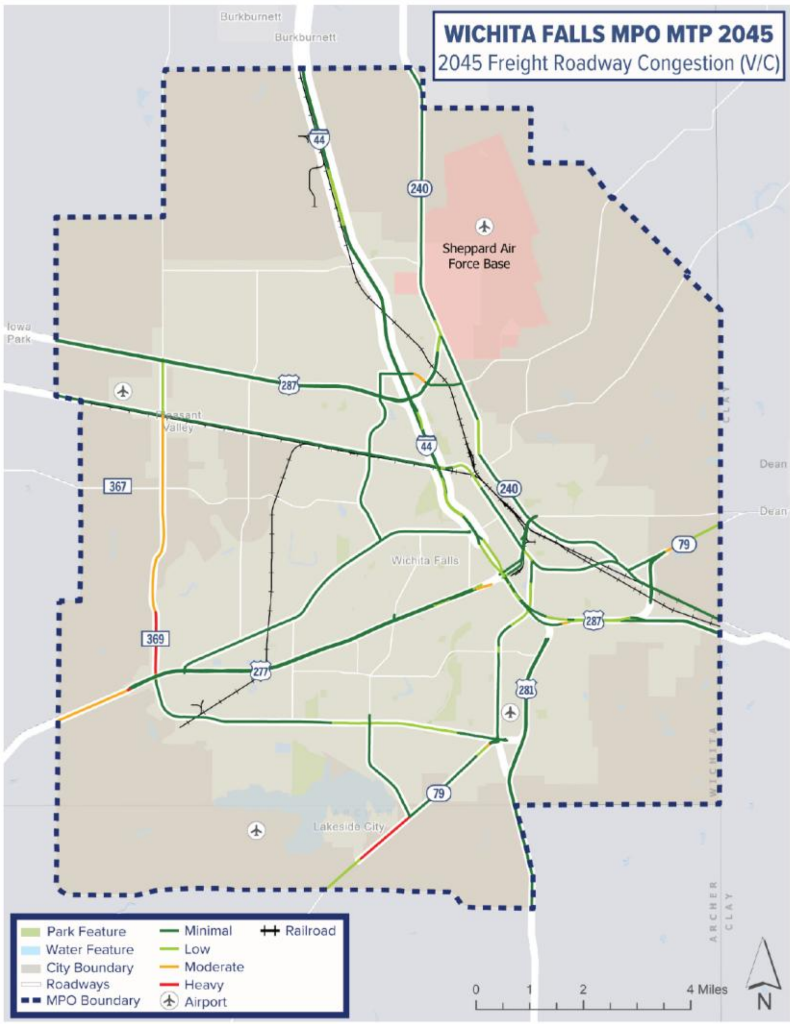


Figure E-10. Wichita Falls Future Freight Network Congestion.

APPENDIX F: TEXAS FREIGHT FLOW MODEL (TFFM) USER GUIDE

USER GUIDE OVERVIEW

Web Application

This user guide for the Texas Freight Flow Model (TFFM) web application (app) was developed as part of Texas Department of Transportation (TxDOT) Project 0-7037: Develop Models for Freight Flows and Commercial Travel Patterns within Texas Urban Regions. The app, developed using Streamlit and deployed on Amazon Web Services (AWS), serves as an interface for end users (planners, engineers, analysts, etc.) to perform analysis on freight commodity flow across Texas for a given year of interest. As outlined in the work plan, the app is currently developed to Technology Readiness Level (TRL) 6, which is defined as a model or prototype demonstration in a relevant environment.

The app can currently be accessed by each analyst using authorized login credentials provided by the Texas A&M Transportation Institute (TTI) research team upon request as outlined in email communications. The TFFM app serves as a front-end/user interface to the TFFM functions developed to this point as a minimum viable product (MVP) prototype, which allows for user interaction through its *Home* page and scenario generation and reporting pages as follows:

- The *Home* page lists all available (executed) and pending user-defined scenarios that TFFM users can access to view previously run corresponding scenario results, reports, and visualizations.
- The *Build New Firm Scenario* page allows analysts to develop a scenario to assess the potential impacts of a new business development introduced into the state of Texas by a specific industry. Users can input information regarding the type of new business and the number of employees for initial analysis using the existing IMPLAN input-output (IO) model. This is the only non-real-time function within the TFFM app process. Once the IMPLAN information for the proposed new firm/location is generated, the results, reports, and visualizations generated for this scenario can be accessed through the *Economic IO Report* and *Flow Report* pages displayed and accessible from the TFFM app *Home* page.
- The *Build Employees Relocation Scenario* page allows analysts to develop a scenario to assess the potential impacts from relocation of an already existing firm within Texas from one county to another county. The results, reports, and visualizations generated for this scenario can again be accessed through the *Economic IO Report* and the *Flow Report* pages accessible from the *Home* page.
- The *Build Transshipment (Warehousing) Scenario* page allows analysts to develop a scenario to assess the potential impacts of redirected flows across industries and geographies resulting from the introduction of new warehouse locations (by county). By

default, the TFFM reports direct flows between producing and consuming counties across all industries. Within this Transshipment Scenario, analysts can assess the influence of additional warehouses (existing or future) in various locations on the flow of commodities between producing and consuming counties. The results, reports, and visualizations generated for this scenario can be accessed through the *Flow Report* page accessible from the *Home* page.

- The *Build Network Closure Scenario* page allows users to evaluate the potential impacts on commodity flows across industries (in non-calibrated truck equivalents) resulting from the closure of one or more highway links in one or both directions. Users can interactively select one or more highway links that they intend to assess for closure impacts and then evaluate the consequent shifts in truck trips across the Texas highway network. The results for this scenario can be accessed through the *Network Closure Report* page accessible from the *Home* page.

Note that each of these scenarios run online through the backend application developed and deployed on the AWS cloud except for the New Firm Scenario. As noted previously, the New Firm Scenario currently requires offline analysis using the IMPLAN software package. Thus, one could expect a few days of lag time for initial New Firm Scenario results, whereas the rest of the scenario analyses should be available to view in near real-time, with a short turnaround time of approximately 5 minutes.

Project Background and Objectives

The objective of this research was to first develop an MVP that could quickly return freight commodity flow data in response to short-term analysis needs. This development was pursued as continuous improvement and enhancement cycle based on user feedback and a better understanding of their analysis needs, expected response rates, and required precision. As a part of this continuous improvement and progressive elaboration process, not all scenarios were chained or linked but they can be in the future. For example, the Network Closure Scenario included in this MVP only presents network impacts and associated visualizations for the base year and highway closure effects for the base year considering all commodities combined. Going forward, this function could be further integrated with the Firm Relocation and Transshipment (Warehousing) Scenarios to visualize individual commodity flows on the highway network resulting from firms being relocated or warehouses being introduced. The research team could pursue these improvements and enhancement efforts through further engagement with the stakeholders, as outlined in *TxDOT Project 0-7037 Technical Memorandum 8*. This work could be done as part of an implementation project to increase the current TRL of the TFFM beyond TRL 6, as outlined in the workplan.

Prior to undertaking the above enhancements, this user guide aims to familiarize potential end users of the TFFM with the existing MVP application and its functionalities—particularly the web app and its utility in generating scenarios, accessing resulting outputs, and reviewing associated reports. Thus, the remainder of this user guide serves as reference for this purpose, walking through each of the previously mentioned scenarios with examples. For each scenario module, a description of its function, input form, and result and reports is provided. The function subsection broadly summarizes the utility of that module. The input form subsection describes step by step how to generate a scenario through the user input forms on the app. The results and reports subsection demonstrates how to go about accessing the results and reports generated for a developed scenario for further analysis and visualization.

HOME PAGE

Function

The *Home* page serves as an interface to access all available (executed) and pending user-defined scenarios that analysts can access/download to view previously run corresponding scenario results, reports, and visualizations. This page is also the landing page when a user logs into the system website at https://tffm.ttihtp.net (Figure F-1).

Figure F-1. Screenshot of Home Page Showing Login Prompts.

Input Form

The *Home* page is divided into two frames (Figure F-2). The left frame provides navigation options for the *Home* page as well as access to pages to build specific scenarios. The right frame of the *Home* page is divided into two sections: *Available Scenarios* and *Pending Scenarios*. *Available Scenarios* (top section) includes user-specified scenarios that have been executed, with reports and results accessible to the analyst. *Available Scenarios* also includes base year scenarios produced using base year IMPLAN data, along with template scenarios as reference examples. The base year scenarios are used to compare against any analyst-submitted (user-specified) scenario generated for a given year of interest. Additional user-specified and named scenarios that have previously been run will also appear here and will be available for selection as well.

Pending Scenarios (bottom section) includes scenarios that are currently in progress. This section primarily includes Build New Firm Scenario types; due to its the reliance on offline analysis using the IMPLAN software package, it takes relatively longer to execute this type of scenario compared to the other scenario types. The other scenario types typically transition from pending to available within a short duration because they are executed in the backend application hosted on AWS cloud services.

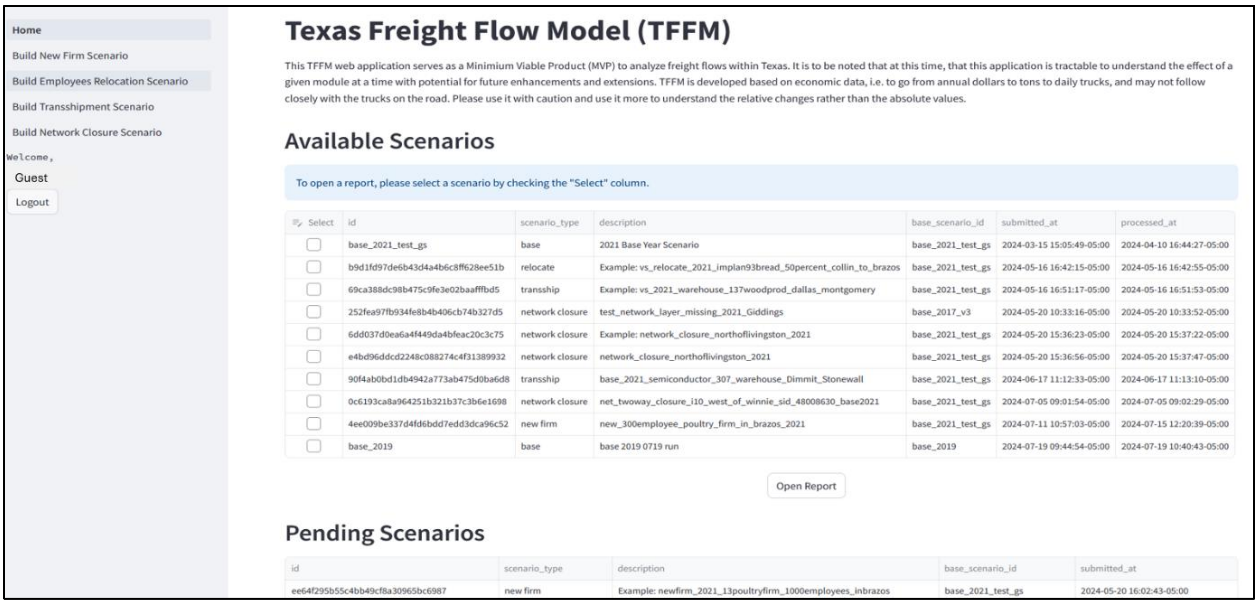


Figure F-2. Screenshot of *Home* Page Showing Available and Pending Scenarios Sections.

Results and Reports

Users can access reports generated for the executed scenarios through the following steps in the TFFM app (Figure F-3):

1. Go to the *Home* page in the app.
2. Select/check the box next to the scenario *id* for which you want to see the results.
3. Select the desired report from the *Select Report* drop-down menu below the list of scenarios.
4. Click the *Open Report* button next to the *Select Report* drop-down menu.

These steps will lead the user to the corresponding report page. Users can choose one of the three reports: *Economic IO, Flow, and Network Closure.*

The *Economic IO Report* page presents the production and consumption tonnage results for the base year and for the executed scenario regarding an industry of interest. The *Economic IO Report* page presents the results in the following formats:

- Tabular format, with the ability to download the outputs in a comma-separated value (CSV) file format.
- Heat map visualization format, showing outputs at the county level statewide in Texas.

Note that the visualizations in the TFFM app currently default productions and consumptions to the county centroid; users can download the outputs in CSV file format to produce their own custom visualizations or further analyze the data.

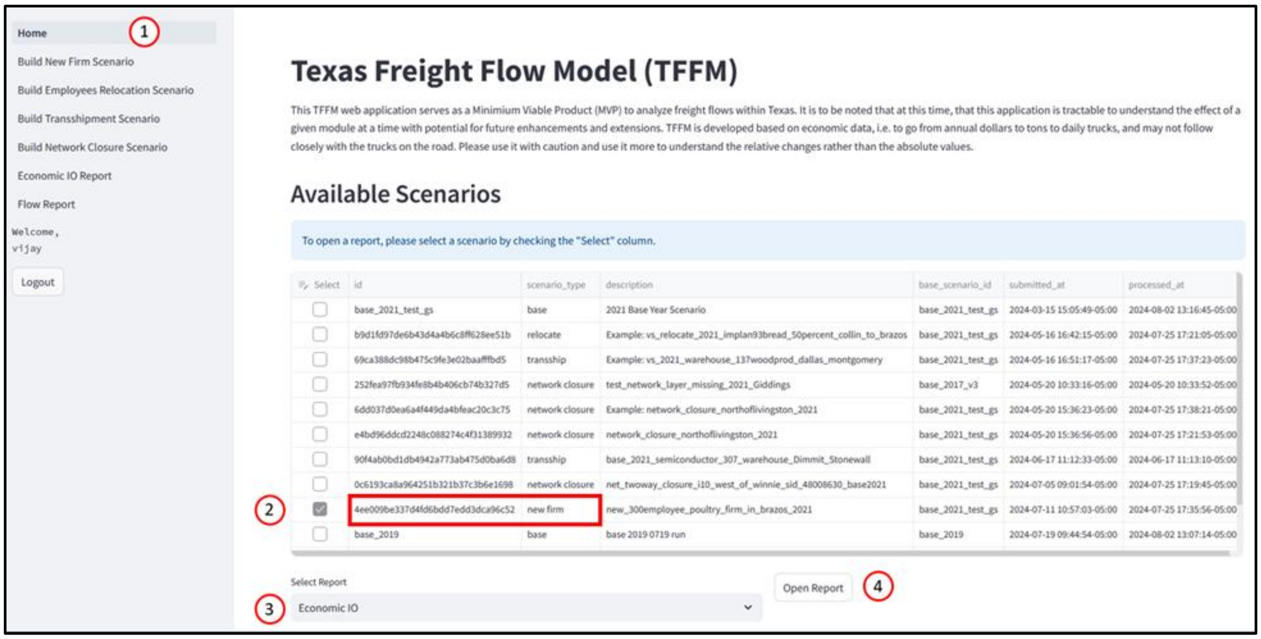


Figure F-3. Screenshot of Home Page Showing Process for Accessing Reports.

The *Flow Report* page presents the commodity distribution results in terms of tons of flow between counties by industry. By default, this module generates direct flows for each industry and can be compared against the transshipment (or warehousing) flow produced because of the user-specified scenario. The *Flow Report* page presents the origin-destination flow results for the base scenario (direct) and the user-defined scenario (warehousing) condition in the following formats:

- Tabular format for each flow scenario, with the ability to download the outputs in a CSV file format.
- Flow map visualization for each scenario, showing outputs at the county level statewide in Texas.

- Interactive chord diagram format, illustrating the top county-to-county flows for each scenario.

The interactive chord diagrams allow users to select a county and highlight specific flows for detailed examination, with the ability to download these charts as an image file for further use.

The *Network Report* page presents the results of the total commodities flowing between counties across the state. These commodities are represented in terms of truck equivalents estimated using a tons-to-truck conversion procedure analogous to the procedure used in the nationwide Freight Analysis Framework using Vehicle Inventory and Use Survey data. This module currently functions to assess the change in network flow across all commodities resulting from the closure of one or more state highway network links. The *Network Report* page presents the results in the following formats:

- Tabular format, listing the top 20 segments identified to have a change in flow for a user-defined closure scenario relative to the base scenario. The user can expand or contract this list through a filter.
- Paired map visualization format, showing the change in link-level flows for a user-defined closure scenario relative to the base scenario. The user defines the link or links that need to be closed.

More details regarding results and reports can be found in each of the respective scenario sections later in this user guide.

NEW FIRM SCENARIO

Function

The establishment of a new business in a specific industry and location will affect the transportation network. The degree of this impact is influenced by the business's size, the industry it belongs to, and its function within the primary industry’s supply chain.

The *New Firm Scenario* page in the app allows users to select the base year, industry type, number of employees, and location (a specified Texas county) for the proposed business. Users are advised to provide a detailed scenario description/unique name to ensure that the IMPLAN results are easily identifiable when the results are posted for use/report generation in the TFFM app’s available scenarios list.

When the *Submit Scenario* button is clicked, the app emails details of the user’s new business scenario to the research team for offline analysis using the IMPLAN software package. This scenario module differs from the other scenario modules because it requires offline processing that results in some lag time (see Pending Scenarios in Figure F-4) compared to the short, near real-time generation results of the other scenarios. After the offline analysis is completed, the results are entered into the backend application and processed to generate production, consumption, and resulting flow estimates for comparison and assessment. The new scenario can then be selected from the *Available Scenarios* section of the *Home* page.

Input Form

Step 1: Build New Firm Scenario

Select *Build New Firm Scenario* from the left sidebar of the *Home* page (see ① in Figure F-4). Selecting this option opens the *Build New Firm Scenario* generation page in the right frame. The next series of steps involve populating individual parameters to execute the scenario.

Step 2: Select Base Scenario

From the base scenario drop-down menu (see ② in Figure F-4), choose a base scenario upon which the New Firm Scenario will be applied. The drop-down menu features several optional base years, determined by the availability of Texas data from IMPLAN and the year of interest.

Step 3: Select IMPLAN Industry

From the industry drop-down menu (see ③ in Figure F-4), select the type of industry for which the impact on transportation will be examined when newly built in a specified county. Note that this drop-down menu currently includes only selected/top IMPLAN industries operating in Texas. Additional industries could be added as enhancements to the TFFM in the future.

Step 4: Select New Firm County

From the county drop-down menu (see ④ in Figure F-4), select the Texas county in which the new firm will be located for the model scenario. At this level of model development, only one new firm county can be selected per scenario.

Step 5: Enter the Industry Size

Enter the industry size/potential number of employees (see ⑤ in Figure F-4) for the new industry to be located in the county.

Step 6: Create Scenario Description

Finally, enter a brief description/unique name for the New Firm Scenario in the textbox field (see ⑥ in Figure F-4). This description helps identify and locate the scenario on the *Home* page once the report is returned and ready for viewing.

Step 7: Submit Scenario

After completing steps 1–6, click the *Submit Scenario* button (see ⑦ in Figure F-4). The system will then send the information to the research team. Once the offline IMPLAN analysis is completed, the results will be available to view in the TFFM app's report section accessible through the *Home* page (see Results and Reporting section). These results will provide valuable insights into the changes in economic distributions and flows attributable to the addition of the new business.

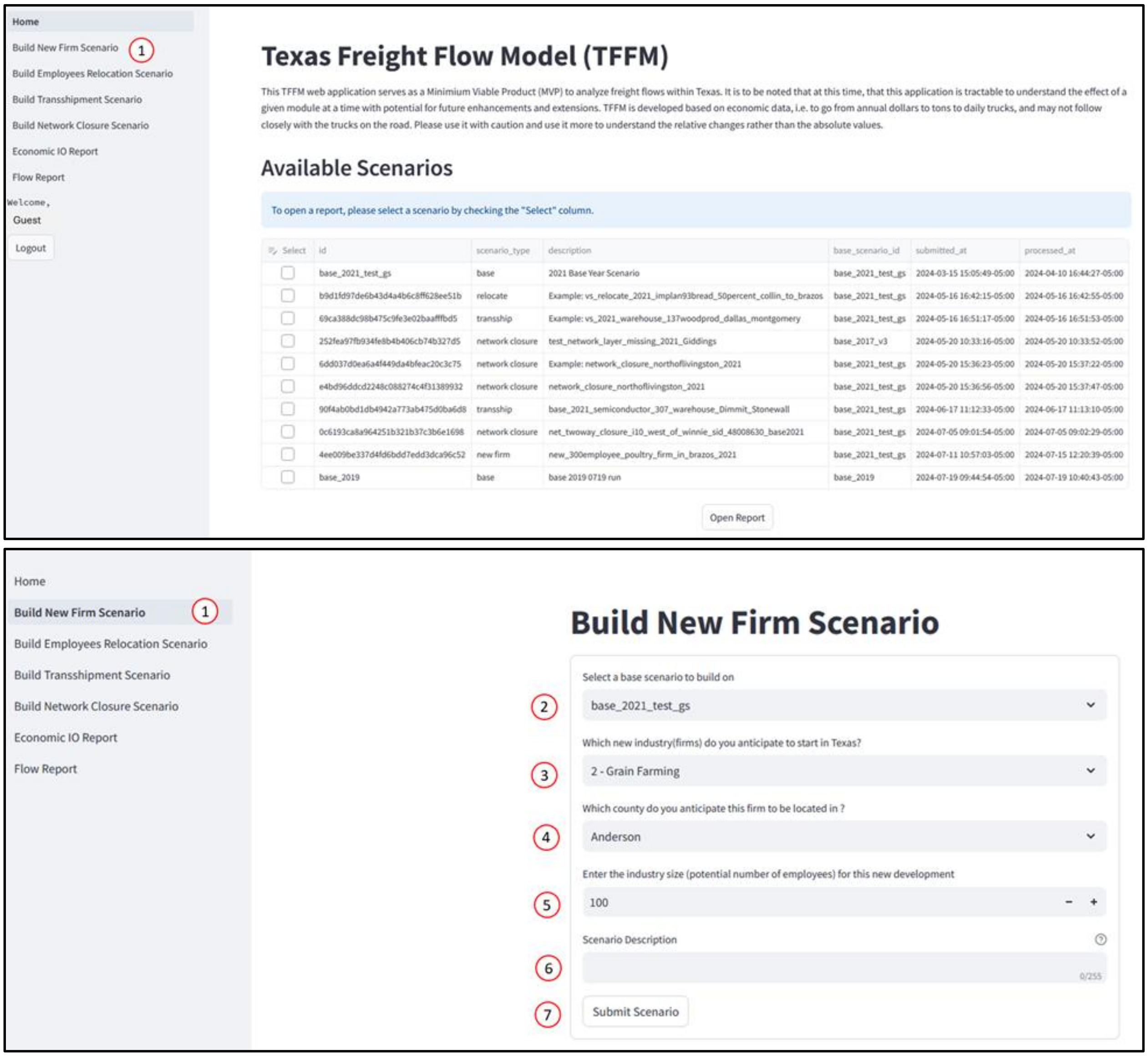


Figure F-4. Screenshots of the *Build New Firm Scenario* Steps.

Results and Reporting

The New Firm Scenario yields results and reports identical to the results and reports produced for the base year because both are initiated through the offline IMPLAN analysis process. In essence, the New Firm Scenario results in updated base year inputs for other backend TFFM functions including all industries, but only the parameters associated with the specific industry in which the new firm is being introduced and the location (Texas county) of the new firm are updated. One development objective is to include all industries—not just that of the new firm—because the addition of the new firm could also influence the flow of commodities from one or more other industries.

The TFFM MVP app currently considers one industry at a time. Theoretically, multiple new firms would be added each year across multiple locations. The ability to analyze more than one industry at a time could be introduced in future TFFM enhancements based on user experience and the need to understand and assess such scenarios as discussed in *TxDOT Project 0-7037 Technical Memorandum 8* and *Final Report (R1)*. The figures and associated discussion in this section present examples of the results generated for the base year; the same set of reports would need to be accessed for each New Firm Scenario as well.

Two main report pages—*Economic IO Report* and *Flow Report*—provide access to the results, maps, and chord diagrams for all industries based on the IMPLAN analyses for the base year and the New Firm Scenario. The steps to access these reports and visualizations are discussed in the remainder of this section, using Figure F-5 as a reference.

Step 1: Go to Home Page

Access the *Home* page by default when logging into the TFFM app or by clicking the navigation link in the left sidebar of the *Home* page (see ① in Figure F-5) if already logged into the app.

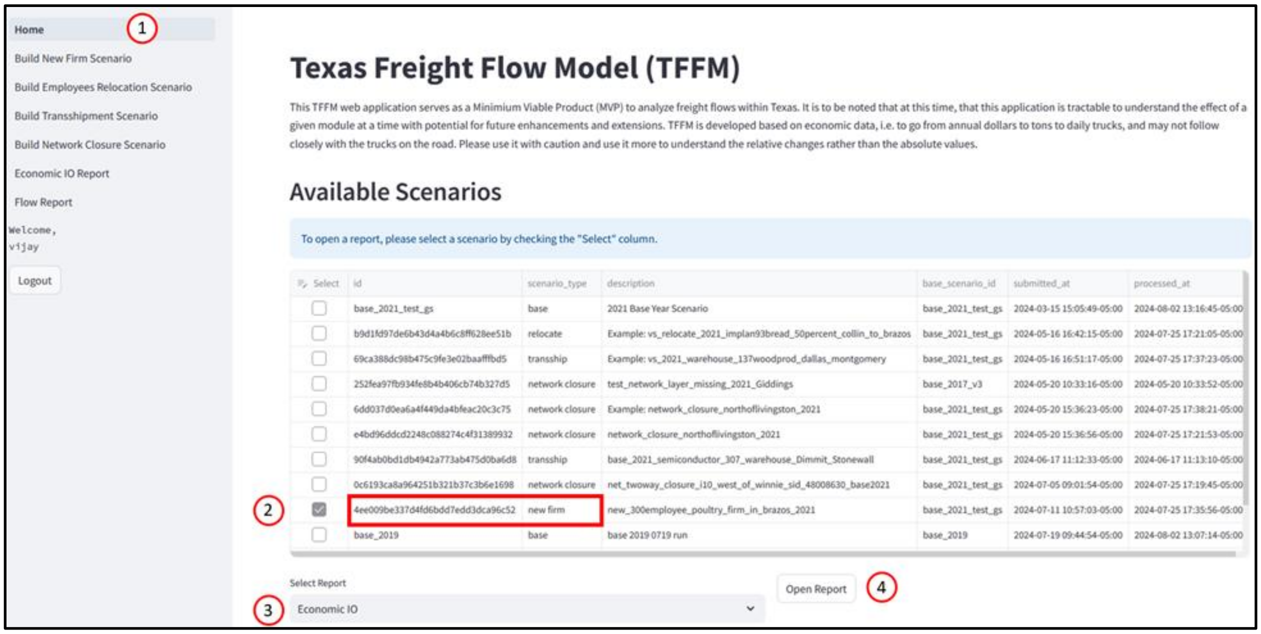


Figure F-5. Screenshot of Base Year and New Firm Scenario Report Selection Steps.

Step 2: Select Scenario

To select the example base scenario, *base_2021_test_gs*, from all scenarios listed under *Available Scenarios*, click the check box next to the appropriate *id* (see ② in Figure F-5). The user should select a scenario that is categorized as either *base* or *new firm* under *scenario_type* on this page.

Step 3: Select Report Type

Select the type of report available for the base year and New Firm Scenario from the drop-down menu (see ③ in Figure F-5). The user can choose either the *Economic IO Report* or the *Flow Report*; these two reports cannot be opened simultaneously but can be viewed sequentially.

Step 4: Open Report

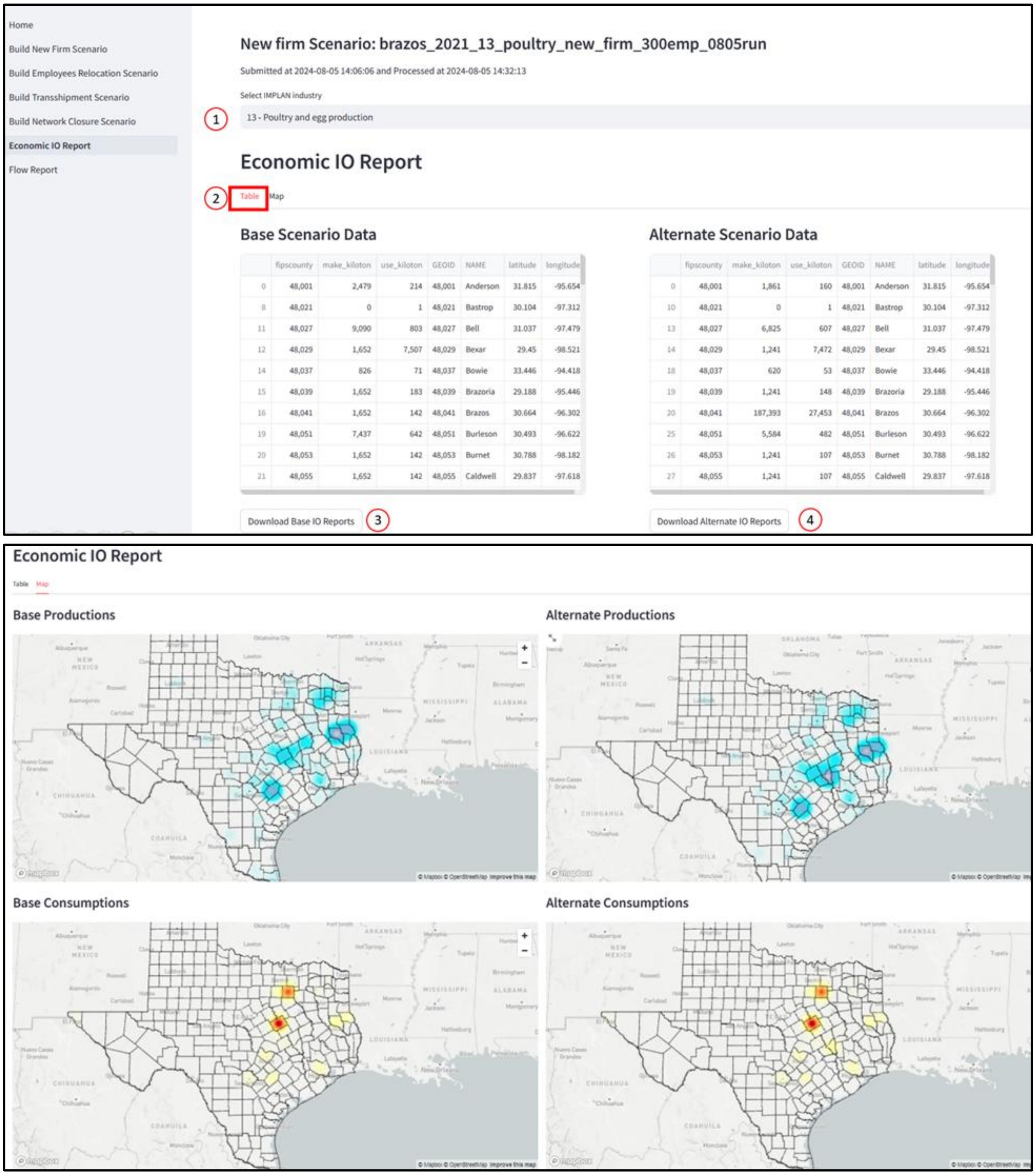
Next, click the *Open Report* button (see ④ in Figure F-5). Based on their report selection, the user is directed to either the *Economic IO Report* page or the *Flow Report* page.

Economic IO Report

Figure F-6 shows the reporting options and outcomes available on the industry specific *Economic IO Report* page for a given base year or New Firm Scenario.

The user can customize the reporting as follows:

1. Select one of the multiple available industries from the drop-down menu (see ① in Figure F-6). For a New Firm Scenario, the user should choose the specific industry related to the new firm.
2. Choose to view made/used or estimated productions and consumptions of commodities by county as a summary table or a map by clicking the *Table* or *Map* buttons (see ② in Figure F-6).
3. Download the results for the selected industry for either the base year or the New Firm Scenario by clicking the *Download Base IO Reports* or *Download Alternate IO Reports* buttons (see ③ and ④ in Figure F-6, respectively). The user can change the selected industry (see ① in Figure F-6) and repeat this process for further custom use and analysis.



Base Scenario Data

	fipscounty	make_kiloton	use_kiloton	GEOID	NAME	latitude	longitude
0	48,001	2,479	214	48,001	Anderson	31.815	-95.654
8	48,021	0	1	48,021	Bastrop	30.104	-97.312
11	48,027	9,090	803	48,027	Bell	31.037	-97.479
12	48,029	1,652	7,507	48,029	Bexar	29.45	-98.521
14	48,037	826	71	48,037	Bowie	33.446	-94.418
15	48,039	1,652	183	48,039	Brazoria	29.188	-95.446
16	48,041	1,652	142	48,041	Brazos	30.664	-96.302
19	48,051	7,437	642	48,051	Burleson	30.493	-96.622
20	48,053	1,652	142	48,053	Burnet	30.788	-98.182
21	48,055	1,652	142	48,055	Caldwell	29.837	-97.618

Alternate Scenario Data

	fipscounty	make_kiloton	use_kiloton	GEOID	NAME	latitude	longitude
0	48,001	1,861	160	48,001	Anderson	31.815	-95.654
10	48,021	0	1	48,021	Bastrop	30.104	-97.312
13	48,027	6,825	607	48,027	Bell	31.037	-97.479
14	48,029	1,241	7,472	48,029	Bexar	29.45	-98.521
18	48,037	620	53	48,037	Bowie	33.446	-94.418
19	48,039	1,241	148	48,039	Brazoria	29.188	-95.446
20	48,041	187,393	27,453	48,041	Brazos	30.664	-96.302
25	48,051	5,584	482	48,051	Burleson	30.493	-96.622
26	48,053	1,241	107	48,053	Burnet	30.788	-98.182
27	48,055	1,241	107	48,055	Caldwell	29.837	-97.618

Figure F-6. Screenshots of Base Year and New Firm Scenario *Economic IO Report* Page and Results.

Flow Report

Figure F-7 shows the reporting options and outcomes available on the industry specific *Flow Report* page for a given base year or New Firm Scenario.

The user can customize the reporting as follows:

1. Select one of the multiple available industries from the drop-down menu (see ① in Figure F-7). For a New Firm Scenario, the user should choose the specific industry related to the new firm.
2. Choose to view commodity flows as a summary table, a map, or a chord diagram by clicking the *Table*, *Map*, or *Chord Diagram* buttons (see ②, ③, and ④ in Figure F-7, respectively). Unlike the *Economic IO Report*, a *Flow Report* may not be available for each listed industry due to the synthesis of multiple data sources and required supplemental data inputs.
3. Download the results for the selected industry for either the base year or the New Firm Scenario by clicking the *Download Base Flow Reports* or *Download Alternate Flow Reports* buttons (see ⑤ in Figure F-7). For those industries with available data, the user can pursue their own custom visualizations or downstream analyses.

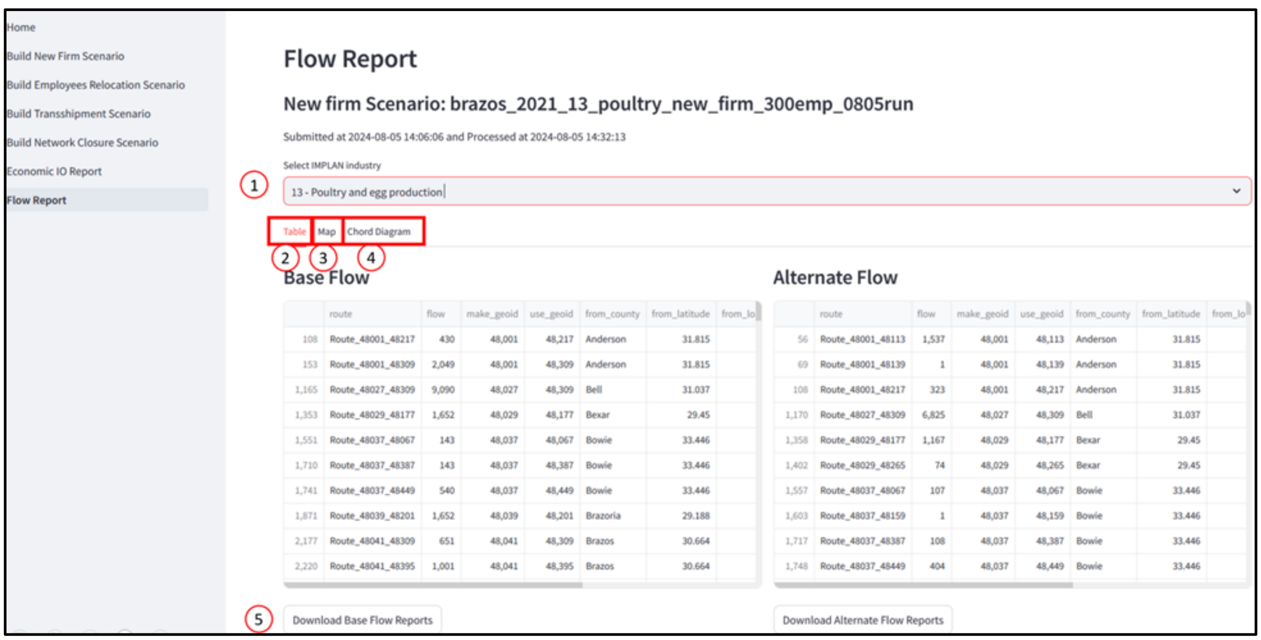
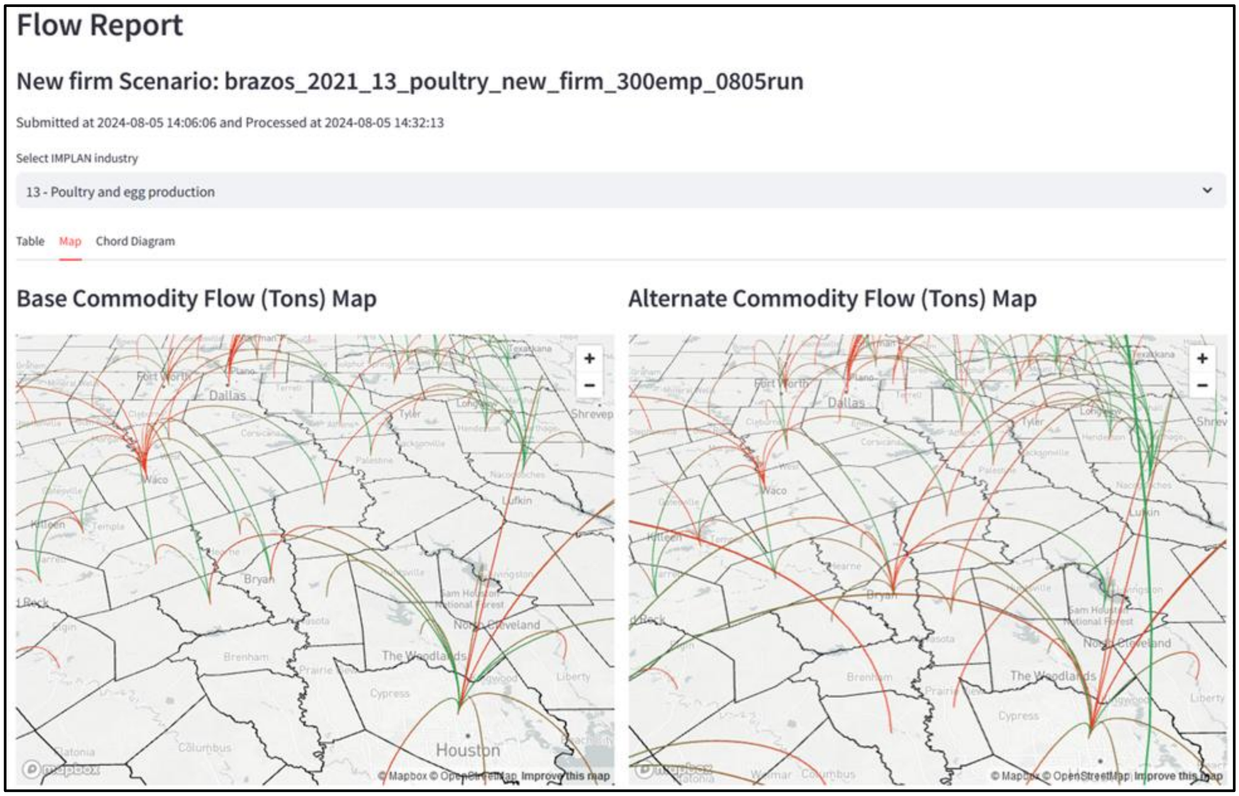


Figure F-7. Screenshots of Base Year and New Firm Scenario *Flow Report*—Maps and Chord Diagrams.



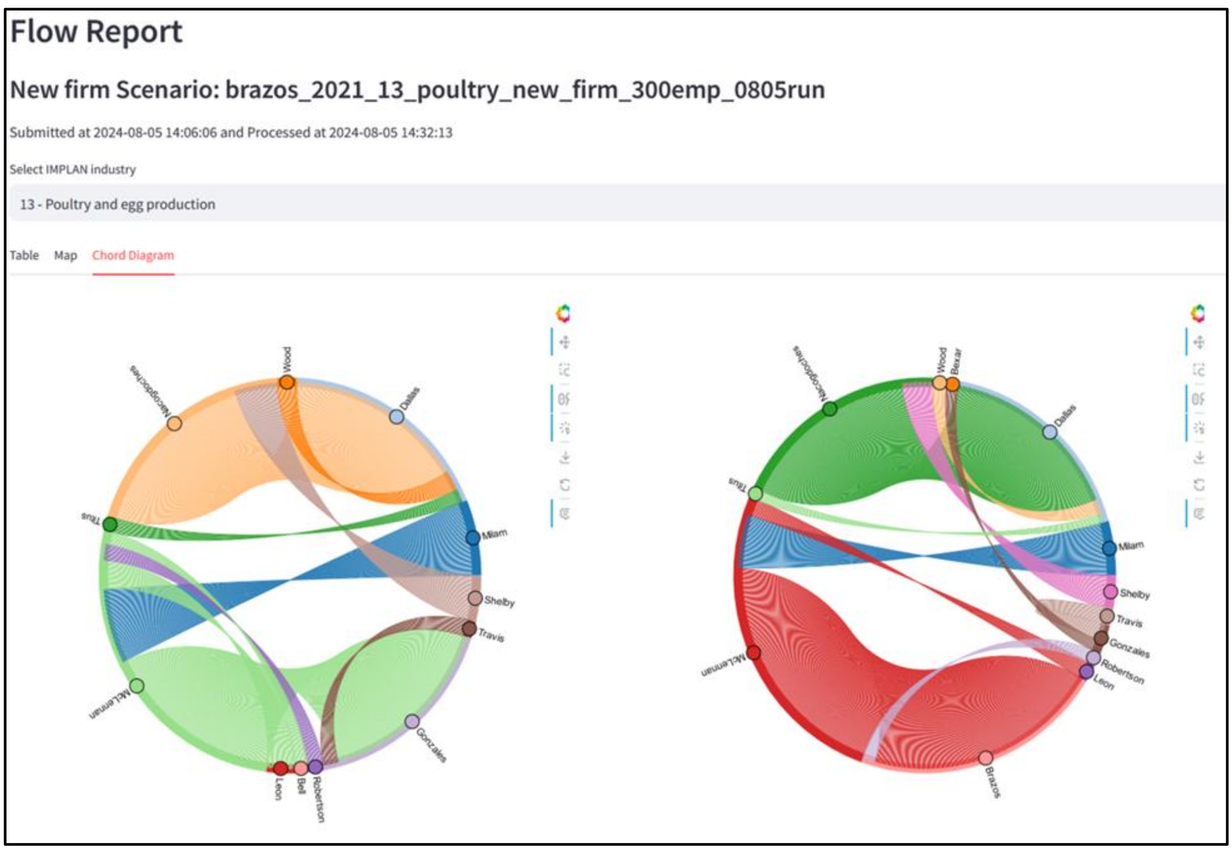


Figure F-7. Screenshots of Base Year and New Firm Scenario *Flow Report*—Maps and Chord Diagrams (Continued).

EMPLOYEES RELOCATION SCENARIO

Function

The Employees Relocation Scenario calculates the impact of relocating an industry (wholly or in part) from one Texas county to another (i.e., when a firm moves its headquarters or part of its operations to a new location). This scenario dynamically assesses the effects on IO distributions and flows. Users must choose a base scenario, specify the industry type, select the origin and destination counties, and indicate the percentage of employees in the industry that are being relocated. Additionally, users are advised to provide a brief description of the scenario to facilitate its identification on the *Home* page once the report is ready for viewing. This process allows for real-time calculation of the relocation's impact, offering valuable insights into economic distribution changes.

Input Form

Step 1: Build Employees Relocation Scenario

Select *Build Employees Relocation Scenario* from the left sidebar of the *Home* page (see ① in Figure F-8). Selecting this option opens the *Build Employees Relocation Scenario* generation page in the right frame. The next series of steps involve populating the parameters to execute the scenario.

Step 2: Select Base Scenario

From the base scenario drop-down menu (see ② in Figure F-8), choose a base scenario upon which the Employees Relocation Scenario will be applied. The drop-down menu features several optional base years, determined by the availability of baseline Texas data from IMPLAN and the year of interest.

Step 3: Select IMPLAN Industry

From the industry drop-down menu (see ③ in Figure F-8), select the type of industry for which the impacts of their employees' relocation to another county will be examined. Note that this drop-down menu currently includes only selected/top IMPLAN industries operating in Texas. Additional industries could be added as TFFM app enhancements in the future.

Step 4: Select Origin County

From the origin county drop-down menu (see ④ in Figure F-8), select the Texas county from which the selected industry employees will be relocated. Only one county can be selected per scenario, and only counties where the selected IMPLAN industry is present appear in the drop-down menu.

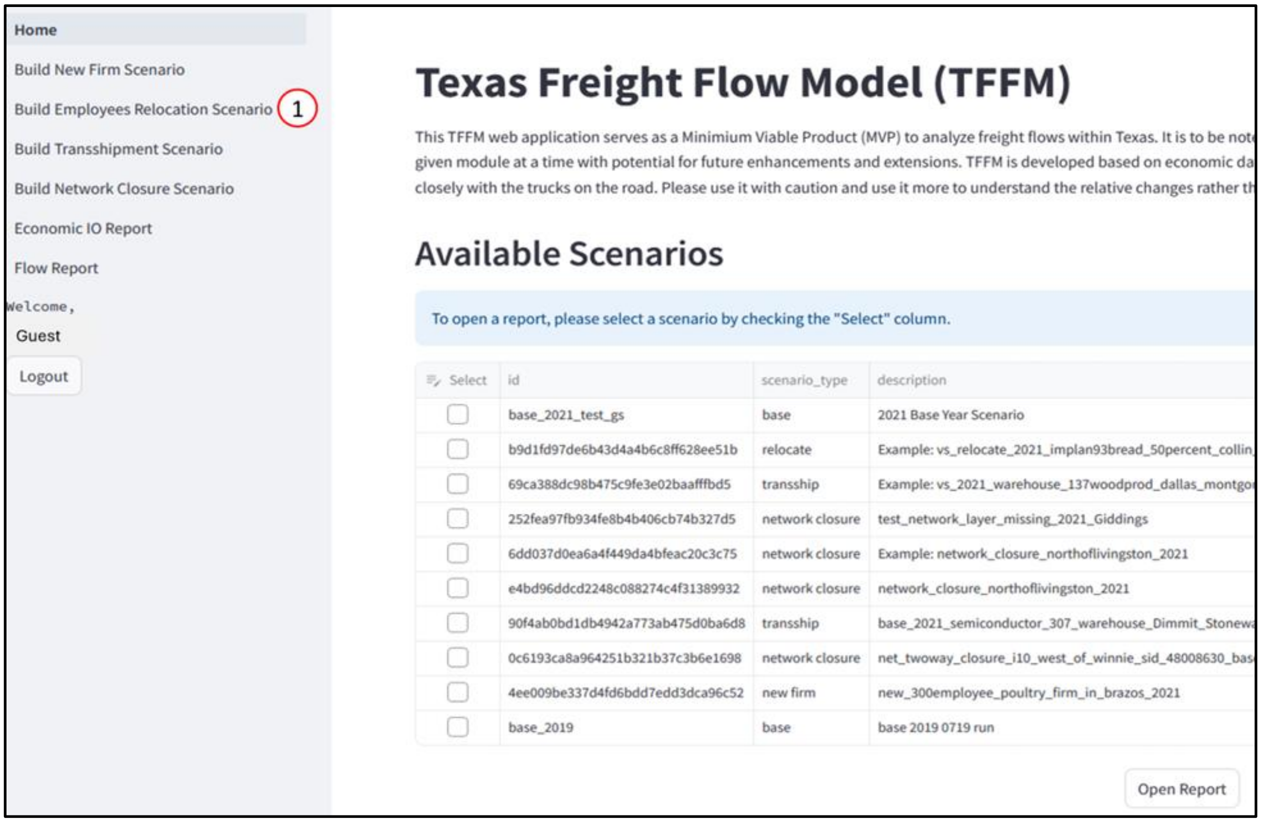


Figure F-8. Screenshots of *Build Employees Relocation Scenario* Steps.

Step 5: Select Destination County

From the destination county drop-down menu (see ⑤ in Figure F-8), select the Texas county to which the selected industry employees will be relocated. Only one county can again be selected per scenario; however, unlike the origin county drop-down menu, the destination county drop-down menu includes all Texas counties.

Step 6: Select Relocation Percentage

In the share of the industry field (see ⑥ in Figure F-8), enter the percentage of employees that will be relocated from one county to another. This parameter determines the scale of the relocation and its impact on distributions and flows. Note that this field requests the *percentage* of existing employees rather than the *number* of existing employees.

Step 7: Create Scenario Description

Finally, enter a brief description/unique name for the Employees Relocation Scenario in the textbox field (see ⑦ in Figure F-8). This description helps identify and locate the scenario on the *Home* page once the report is ready for viewing.

Step 8: Submit Scenario

After completing steps 1–7, click the *Submit Scenario* button (see ⑧ in Figure F-8). The system will then initiate the Employees Relocation Scenario analysis on the cloud-based server and return the outputs on the *Home* page. The analyst is subsequently notified that the analysis is complete through the app.

Results and Reporting

Once the Employees Relocation Scenario has completed its run, it will appear as an option in the list of *Available Scenarios* on the *Home* page. Results are again provided through two main report pages—*Economic IO Report* and *Flow Report*. The steps to access these reports and visualizations are discussed in the remainder of this section, using Figure F-9 as a reference.

Step 1: Go to Home Page

Access the *Home* page by default when logging into the TFFM app or by clicking the navigation link in the left sidebar of the *Home* page (see ① in Figure F-9) if already logged into the app.

Step 2: Select Scenario

To select the example scenario from all scenarios listed under *Available Scenarios*, click the check box next to the appropriate *id* (see ② in Figure F-9). The user should select a scenario that is categorized as *relocate* under *scenario type* on this page with a description that matches the analyst's interests in assessing impacts.

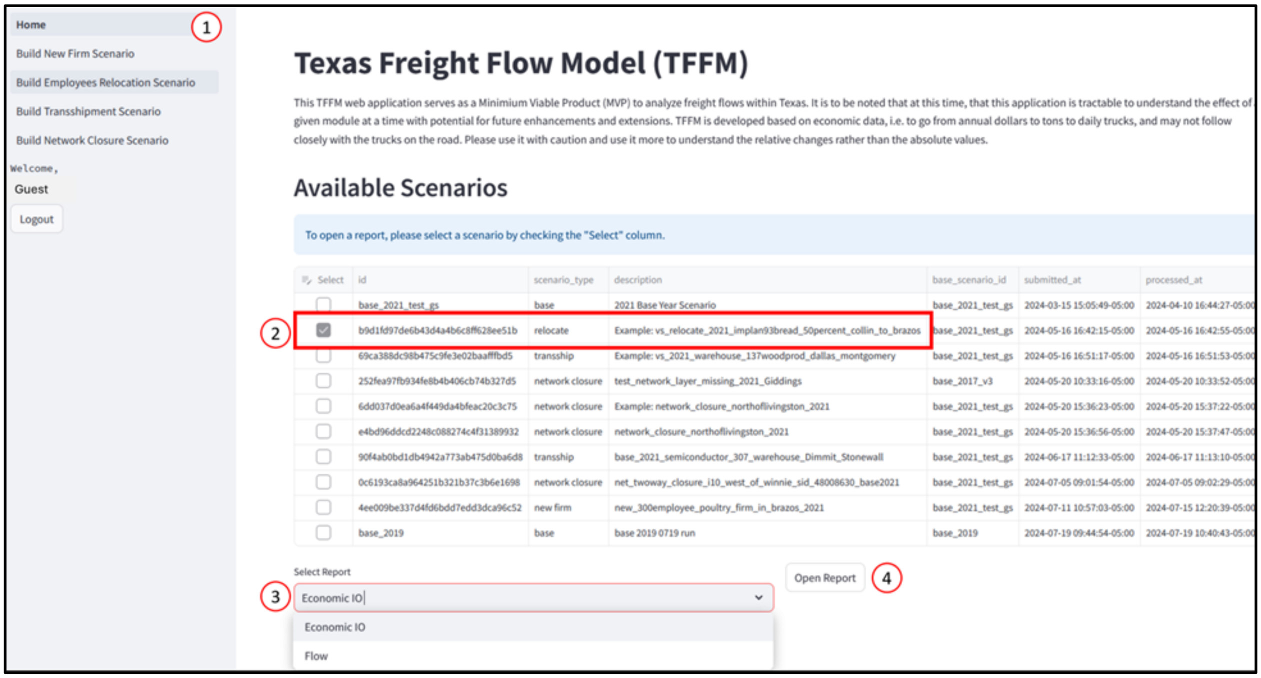


Figure F-9. Screenshot of *Employees Relocation Scenario Report* Selection Steps.

Step 3: Select Report Type

Select the type of report available for the base year and New Firm Scenario from the drop-down menu (see ③ in Figure F-9). The user can choose either the *Economic IO Report* or the *Flow Report*; these two reports cannot be opened simultaneously but can be viewed sequentially.

Step 4: Open Report

Next, click the *Open Report* button (see ④ in Figure F-9) to generate a report. Based on their report selection, the user is directed to either the *Economic IO Report* page or the *Flow Report* page.

Economic IO Report

Figure F-10 shows the reporting options and outcomes available on the industry specific Economic IO Report page for a given base year or Employees Relocation Scenario. Unlike the base year and New Firm Scenario report pages that require the user to select from multiple available industries in a drop-down menu, the Employees Relocation Scenario report page presents only a single specified industry.

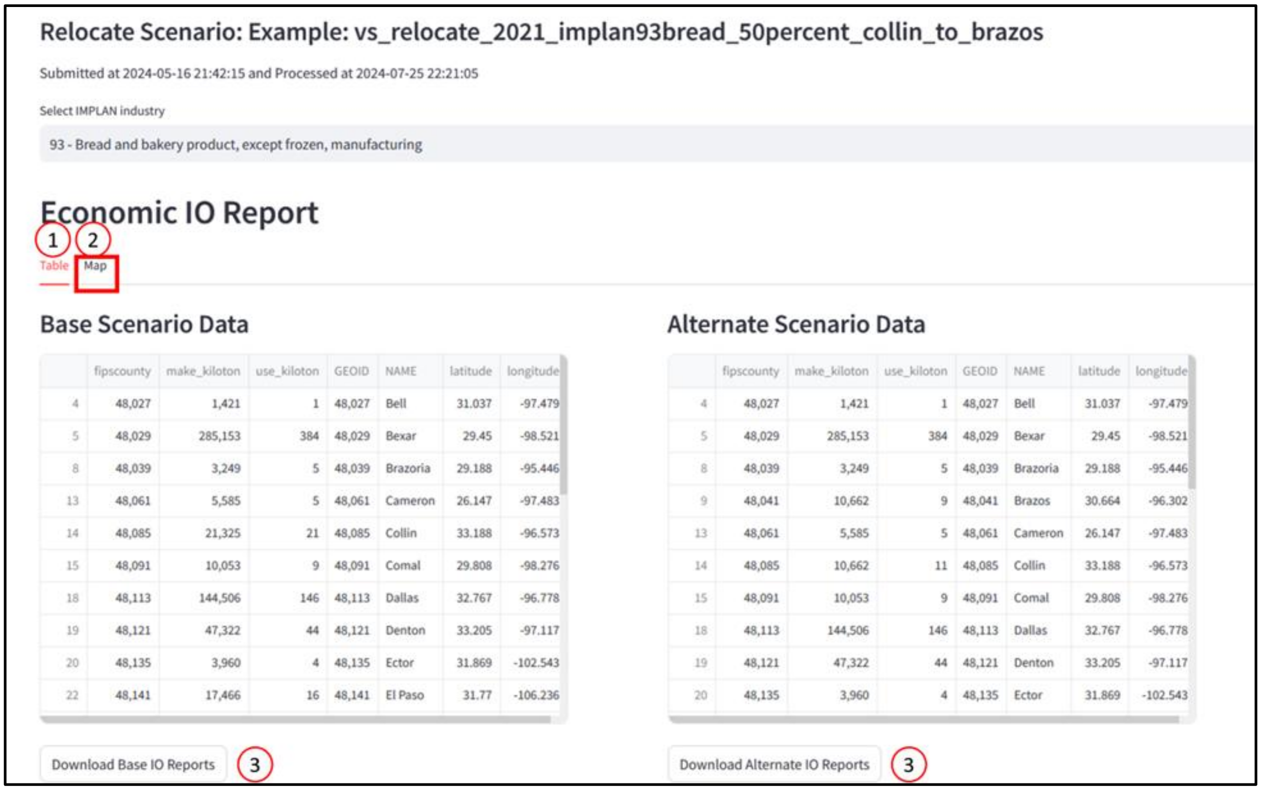


Figure F-10. Screenshots of Base Year and Employees Relocation Scenario *Economic IO Report* Page.

The user can customize the reporting as follows:

1. Choose to view made/used or estimated productions and consumptions of commodities by county as a summary table or a statewide map by clicking the *Table* or *Map* buttons (see ① and ② in Figure F-10, respectively). The second tab compares the results in map format, with the base year results on the left and the Employees Relocation Scenario results on the right.
2. Download the results for the specified industry for either the base year or the Employees Relocation Scenario by clicking the *Download Base IO Reports* or *Download Alternate IO Reports* buttons (see ③ in Figure F-10). The user can download the results table in CSV format for offline use, including producing customized maps.

In the demonstrated example, Figure F-11 shows a decrease in industry production in Collin County and an increase in industry production in Brazos County following the relocation of employees in this scenario. Production distributions in all other counties appear to be the same before and after the relocation. Similar impacts can be observed in the consumption distribution as well.

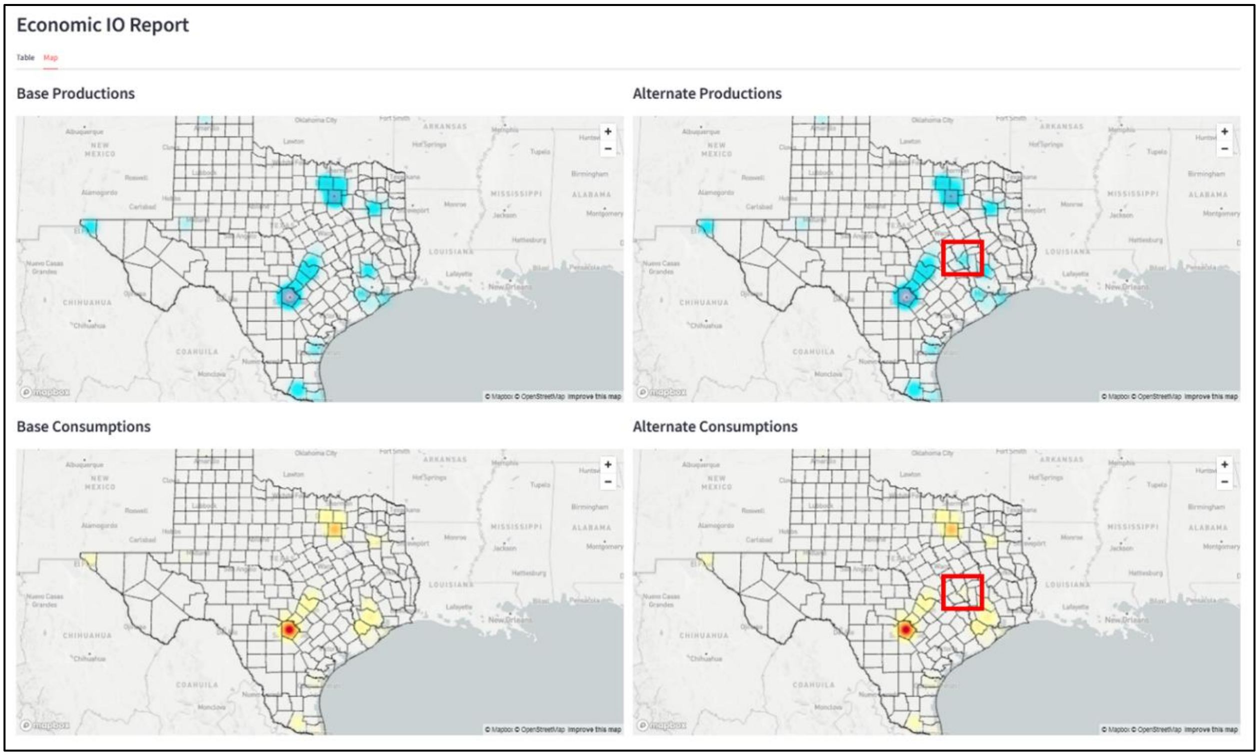


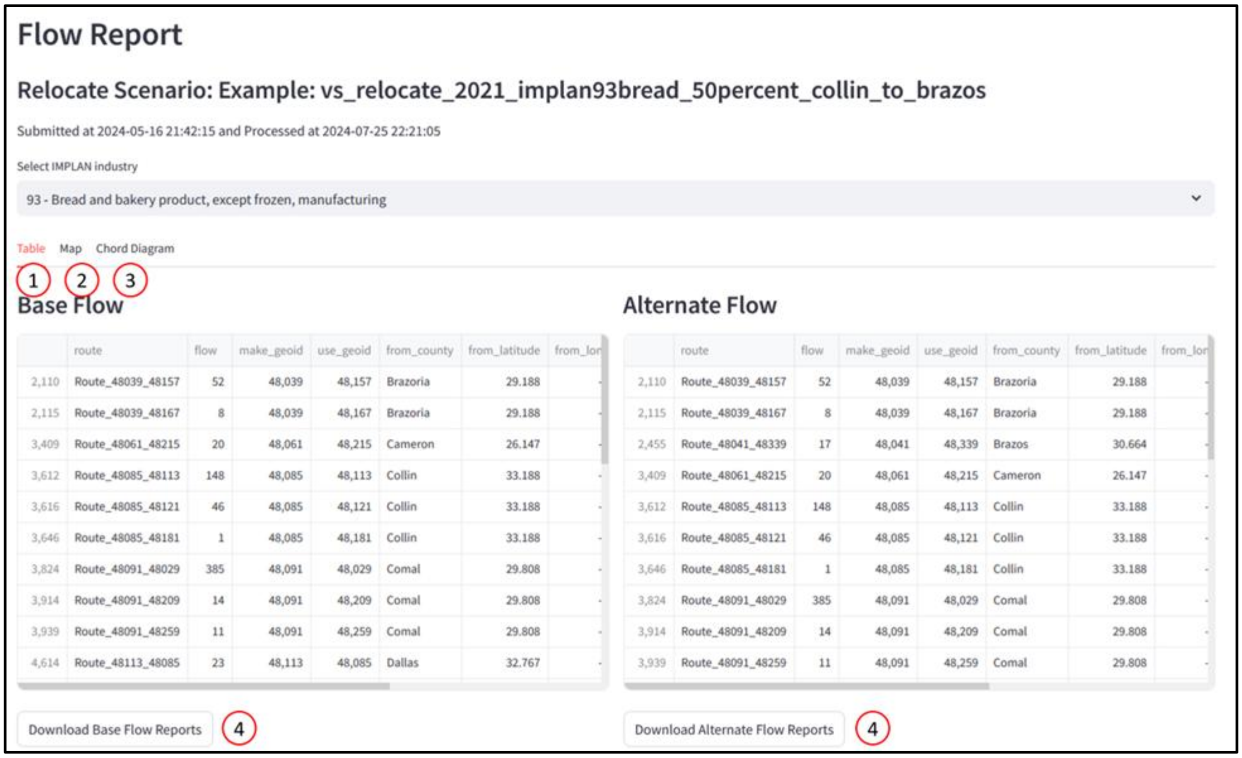
Figure F-11. Screenshots of Base Year and Employees Relocation Scenario *Economic IO Report* Results.

Flow Report

Figure F-12 shows the reporting options and outcomes available on the industry specific *Flow Report* page for a given base year or Employees Relocation Scenario. The user can customize the reporting as follows:

1. Choose to view commodity flows as a summary table, a map, or a chord diagram by clicking the *Table*, *Map*, or *Chord Diagram* buttons (see ①, ②, and ③ in Figure F-12, respectively).
2. Download the results for the selected industry for either the base year or the Employees Relocation Scenario by clicking the *Download Base Flow Reports* or *Download Alternate Flow Reports* buttons (see ④ in Figure F-12).

The tabular results compare the origin-destination (OD) flows—expressed in tons between counties—between the base year and the Employees Relocation Scenario. The map-based results show the base year and scenario flows between counties using arcs, with the green end of the arc representing the origin and red end of the arc representing the destination (Figure F-13). In this example, observe the additional flow in Brazos County following the relocation of employees. Last, Figure F-14 displays the flow results as an interactive chord diagram. This visualization helps the analyst understand the magnitude of the flow across all counties.



Base Flow

	route	flow	make_geoid	use_geoid	from_county	from_latitude	from_lon
2,110	Route_48039_48157	52	48,039	48,157	Brazoria	29.188	
2,115	Route_48039_48167	8	48,039	48,167	Brazoria	29.188	
3,409	Route_48061_48215	20	48,061	48,215	Cameron	26.147	
3,612	Route_48085_48113	148	48,085	48,113	Collin	33.188	
3,616	Route_48085_48121	46	48,085	48,121	Collin	33.188	
3,646	Route_48085_48181	1	48,085	48,181	Collin	33.188	
3,824	Route_48091_48029	385	48,091	48,029	Comal	29.808	
3,914	Route_48091_48209	14	48,091	48,209	Comal	29.808	
3,939	Route_48091_48259	11	48,091	48,259	Comal	29.808	
4,614	Route_48113_48085	23	48,113	48,085	Dallas	32.767	

Alternate Flow

	route	flow	make_geoid	use_geoid	from_county	from_latitude	from_lon
2,110	Route_48039_48157	52	48,039	48,157	Brazoria	29.188	
2,115	Route_48039_48167	8	48,039	48,167	Brazoria	29.188	
2,455	Route_48041_48339	17	48,041	48,339	Brazos	30.664	
3,409	Route_48061_48215	20	48,061	48,215	Cameron	26.147	
3,612	Route_48085_48113	148	48,085	48,113	Collin	33.188	
3,616	Route_48085_48121	46	48,085	48,121	Collin	33.188	
3,646	Route_48085_48181	1	48,085	48,181	Collin	33.188	
3,824	Route_48091_48029	385	48,091	48,029	Comal	29.808	
3,914	Route_48091_48209	14	48,091	48,209	Comal	29.808	
3,939	Route_48091_48259	11	48,091	48,259	Comal	29.808	

Figure F-12. Screenshots of Base Year and Employees Relocation Scenario *Flow Report*—Table.

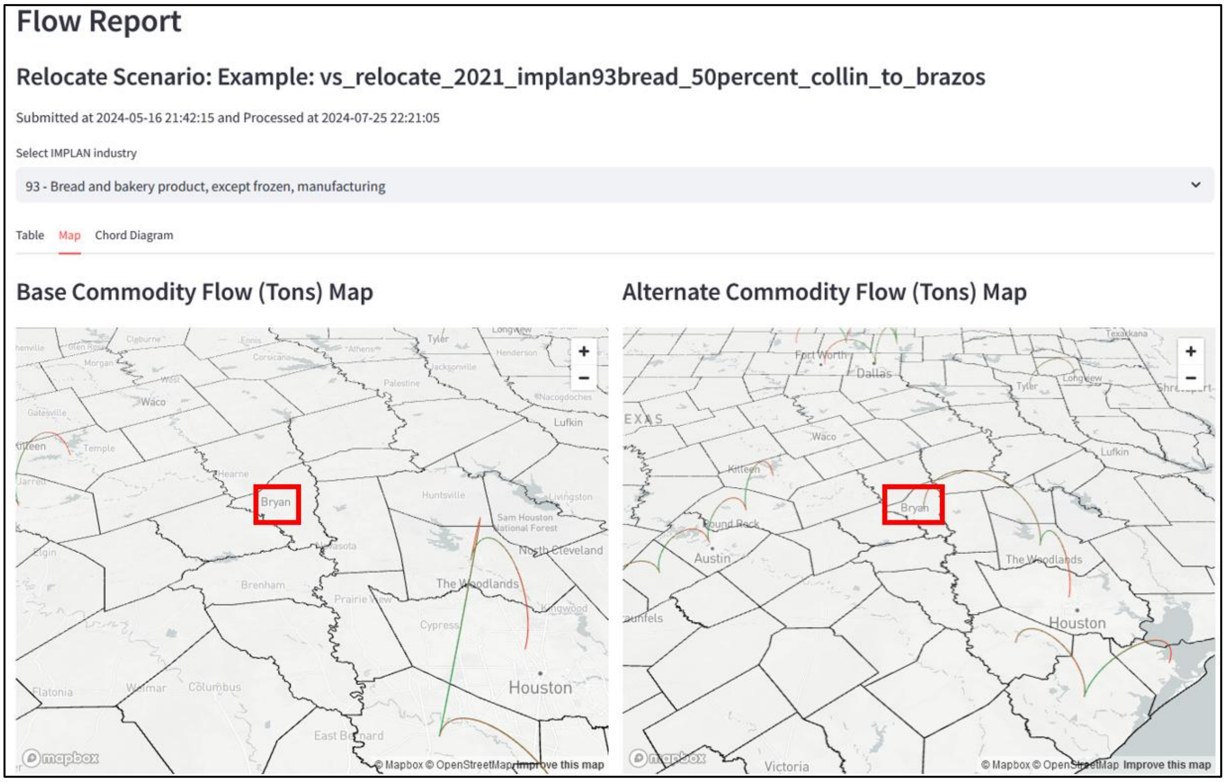


Figure F-13. Screenshots of Base Year and Employees Relocation Scenario *Flow Report*—Map.

Figure F-14. Screenshots of Base Year and Employees Relocation Scenario *Flow Report*—Chord Diagram.

TRANSSHIPMENT SCENARIO

Function

It is often difficult to understand or introduce the effects of transshipment points (warehouses or transfer points) without knowledge of the specific industry and its operations within a given geography. An analyst with experience or background in a specific industry would likely perform much better than an automated procedure using typical or common principles. Thus, this scenario's user interface allows an analyst to understand the influence of warehouses or transfer points for general commodities and their movements while allowing details for specialty items to differ in reality. The TFFM app explicitly calls for the analyst to list the potential counties that they want to consider as points of transfer and submit these counties to the backend model for the app functions to then redistribute the direct flows for the industry of interest.

Note that this analysis occurs at a specific industry level, where an analyst can evaluate the potential shift in county-to-county flows resulting from the introduction of one or more counties as locations for intermediate warehouses between origins and destinations. Figure F-15 shows an example of the potential redistribution of commodity flows resulting from the introduction of two counties as warehouses or points of transfer.

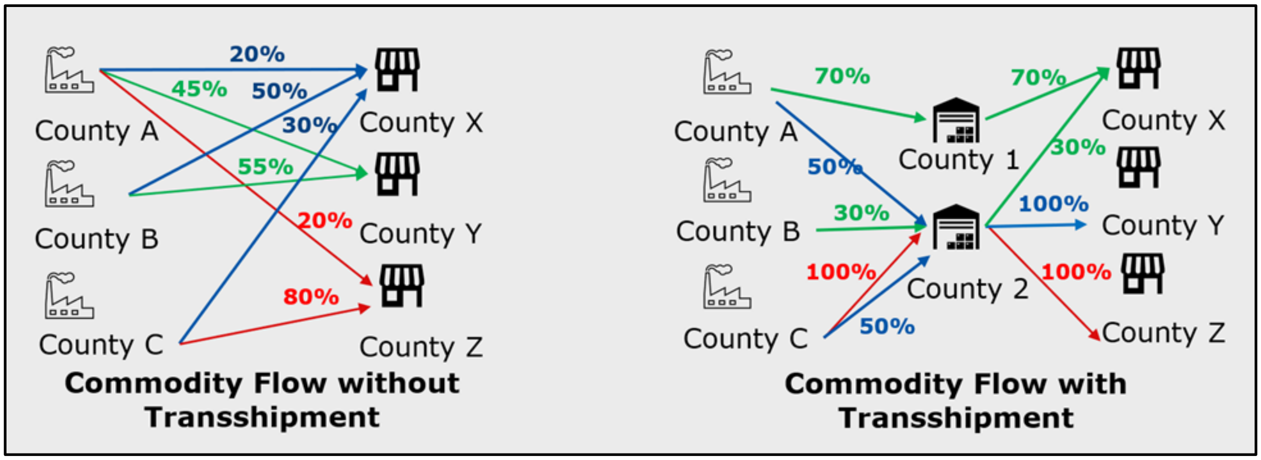


Figure F-15. Example Commodity Flows with and without Warehousing/Transshipment.

Input Form

The example described in the previous section can be implemented through the TFFM app by accessing the *Build Transshipment Scenario* page of the app (Figure F-16).

Step 1: Build Transshipment Scenario

Select *Build Transshipment Scenario* from the left sidebar of the *Home* page (see ① in Figure F-16). Selecting this option opens the *Build Transshipment Scenario* page in the right frame. The next series of steps involve populating the parameters to execute the scenario.

Step 2: Select Base Scenario

From the base scenario drop-down menu (see ② in Figure F-16), choose a base scenario upon which the Transshipment Scenario will be applied. The drop-down menu lists several optional base years, determined by the availability of Texas data from IMPLAN and the year of interest.

Step 3: Select IMPLAN Industry

From the industry drop-down menu (see ③ in Figure F-16), select the type of industry for which the impacts of warehousing in commodity flows will be examined. Note that this drop-down menu currently includes only selected/top IMPLAN industries operating in Texas. Additional industries could be added as TFFM app enhancements in the future.

Step 4: Select Warehousing County

From the warehousing county drop-down menu (see ④ in Figure F-16), select one or more counties that are to be considered as warehousing location(s). Note that counties that produce or consume the commodity from the industry of interest cannot be selected; by default, the scenario generation page filters out these counties from the list of producing counties. Also, the user should avoid selecting too many counties as potential warehousing locations to avoid *no generated solution* issues within the model output.

Step 5: Create Scenario Description

Finally, enter a brief description/unique name for the Transshipment Scenario in the textbox field (see ⑤ in Figure F-16). Ideally, the description would include the base year, industry, and warehousing county names, if feasible.

Step 6: Submit Scenario

After completing steps 1–5, click the *Submit Scenario* button. The system will then initiate the Transshipment Scenario analysis on the cloud-based server and return the outputs on the *Home* page. The analyst is subsequently notified that the analysis is complete through the app.

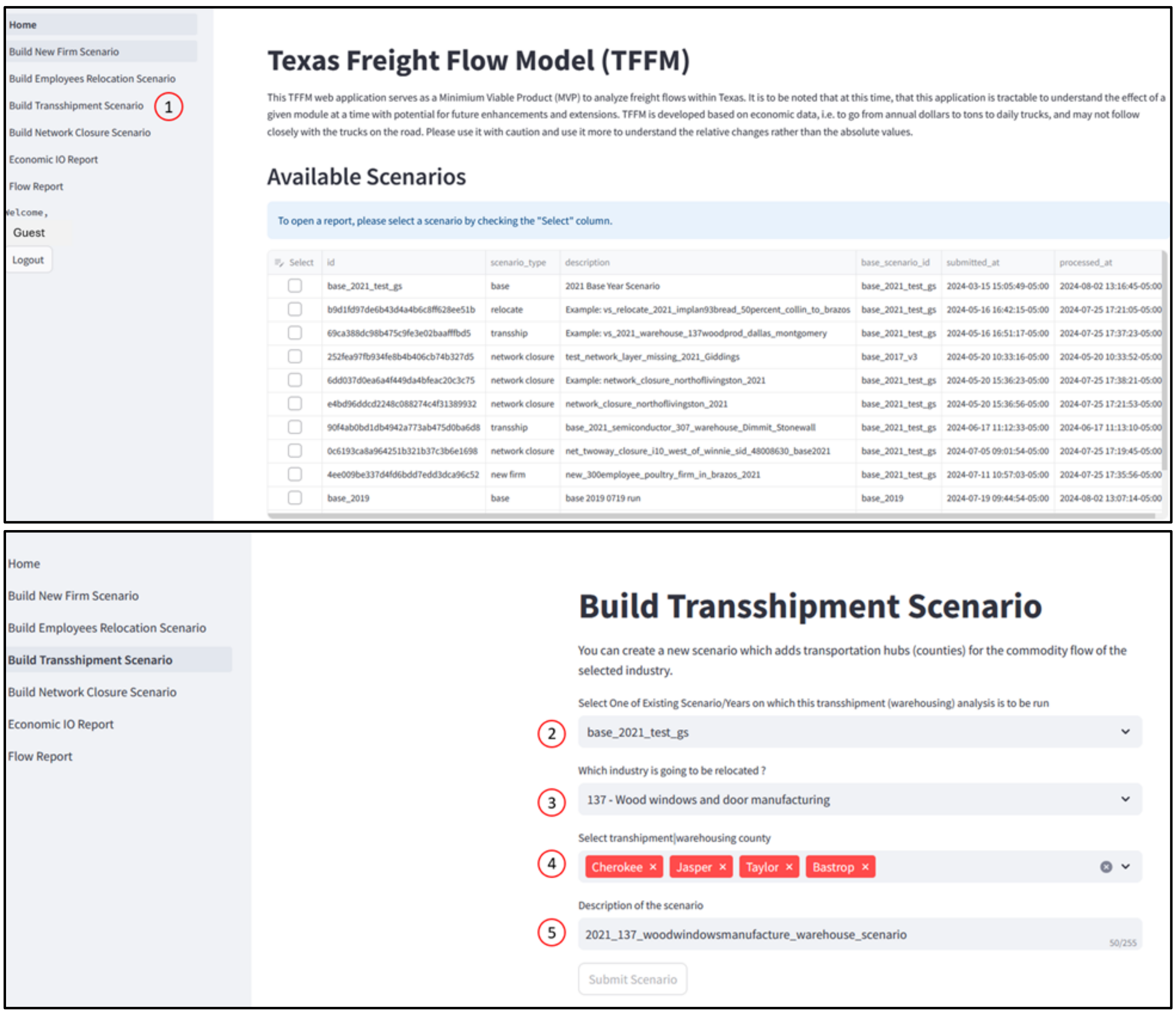


Figure F-16. Screenshots of *Build Transshipment Scenario* Steps.

Results and Reporting

Once the Transshipment Scenario has completed its run, it will appear as an option in the list of *Available Scenarios* on the *Home* page. Results are again provided through two main report pages—*Economic IO Report* and *Flow Report*. For this example, the *Flow Report* is most relevant. The steps to access this report and associated visualizations are discussed in the remainder of this section, using Figure F-17 as a reference.

Step 1: Go to Home Page

Access the *Home* page by default when logging into the TFFM app or by clicking the navigation link in the left sidebar of the *Home* page (see ① in Figure F-17) if already logged into the app.

Step 2: Select Scenario

To select the example scenario from all scenarios listed under *Available Scenarios*, click the check box next to the appropriate *id* (see ② in Figure F-17). The user should select a scenario of interest for further review and assessment that is categorized as *tranship* under *scenario_type* on this page.

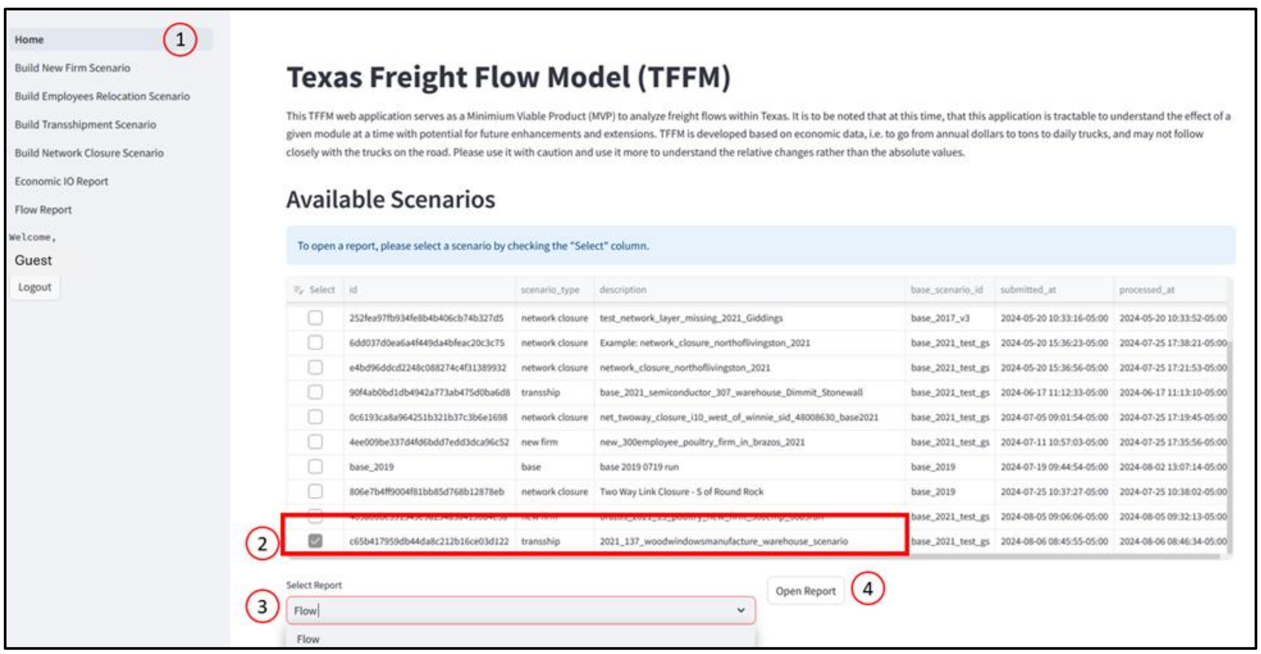


Figure F-17. Screenshot of Transshipment Scenario Report Selection Steps.

Step 3: Select Report Type

Select the type of report available for the base year and Transshipment Scenario from the drop-down menu (see ③ in Figure F-17). The user can choose either the *Economic IO Report* or the *Flow Report*; the *Flow Report* is most relevant for this example.

Step 4: Open Report

Next, click the *Open Report* button (see ④ in Figure F-17) to generate a report. Based on their report selection, the user is directed to either the *Economic IO Report* page or the *Flow Report* page.

Flow Report

Figure F-18 shows the reporting options and outcomes available on the industry specific *Flow Report* page for a given base year or Transshipment Scenario. The user can customize the reporting as follows:

1. Choose to view commodity flows as a summary table, a map, or a chord diagram by clicking the *Table*, *Map*, or *Chord Diagram* buttons (see ①, ④, and ⑤ in Figure F-18, respectively).
2. Download the results for the selected industry for either the base year or the Transshipment Scenario by clicking the *Download Base Flow Reports* or *Download Alternate Flow Reports* buttons (see ② and ③ in Figure F-18, respectively).

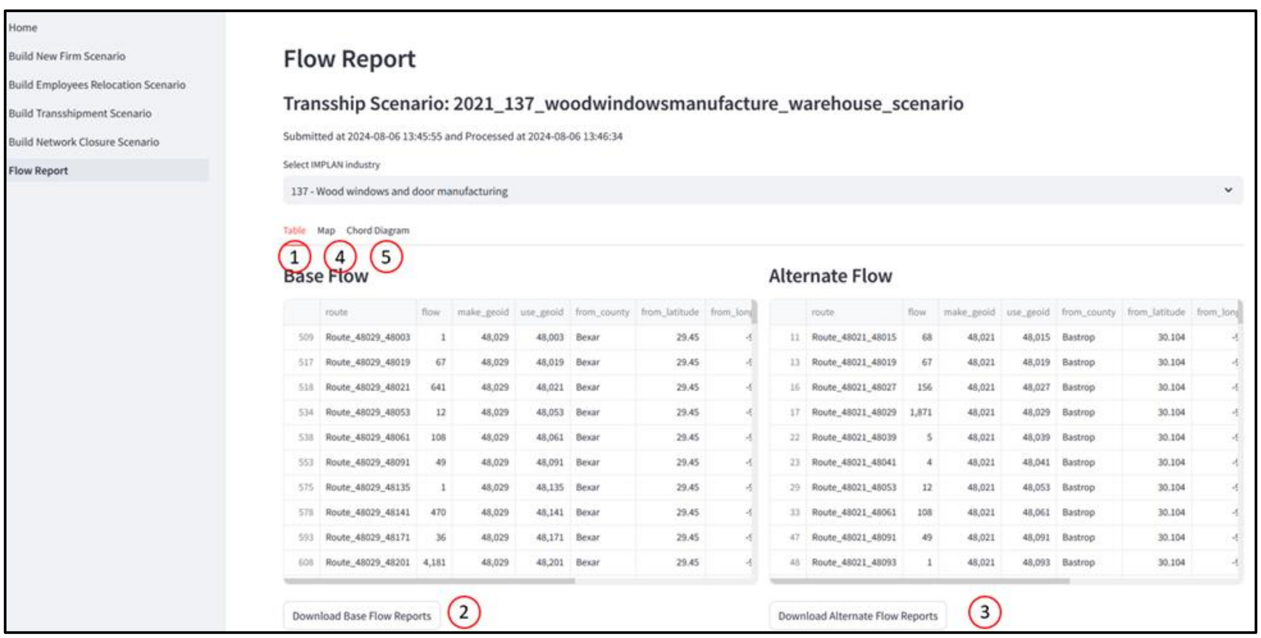


Figure F-18. Screenshot of *Flow Report*—Table.

In the demonstrated example, the *Base Flow* represents direct flows between producing and consuming counties considering the impedance (travel distance) between the counties without any intermediate points of transfer (transshipment or warehousing locations). The *Alternate Flow* represents the flows between counties resulting from the introduction of warehousing location(s). In this example, Dimmit and Stonewall counties were selected by the user as warehouse locations for the semiconductor industry.

The map-based results show noticeable changes in the commodity routes from producing to consuming counties through Dimmit or Stonewall counties (Figure F-19). For the *Base Flow,* commodities predominately originate from the Dallas, Austin, or Houston metro areas. For the *Alternate Flow,* commodities from these prominent origins are primarily redirected to Dimmit and Stonewall counties and then eventually distributed to their destination counties.

These maps are interactive and dynamically generated across industries and scenarios. The green and red ends of the arcs represent the origins and destinations, respectively. The user can also produce their own custom visualizations by downloading the data from the *Table* tab of this report page; each file includes spatial/geographic attributes (e.g., latitude/longitude) as well as flow estimates.

Note that the maps do not directly show the magnitude of flow. To assess flow magnitude, the maps must be combined with chord diagrams (Figure F-20). The interactive chord diagram on the TFFM app allows the user to highlight flows between a selected county (shown in green in the bottom chord diagram) and all other top counties. In this Transshipment Scenario example, Dimmit County warehousing redirects flows between Harris and Travis counties, while Stonewall County warehousing redirects flows around Dallas and neighboring counties.

Implementation of this type of transshipment/warehousing scenario would likely result in a subsequent shift in flow of commodities through the highway network. Thus, it is useful to understand how the introduction of warehouses in the specified county or counties would shift the flow of the input commodity and other commodities across highway links. As an MVP, the TFFM app does not currently integrate transshipments and warehousing with network scenarios.

The Network Closure Scenario module (discussed in the next section) is currently confined to the representation of total flows and the influence of link closure scenarios. Future improvements proposed as part of *TxDOT Project 0-7037 Technical Memorandum 8* during this research included the integration of upstream scenarios—such as firm/employee relocation and transshipment/warehousing initiatives—with the Network Closure Scenario module as recommended next steps.

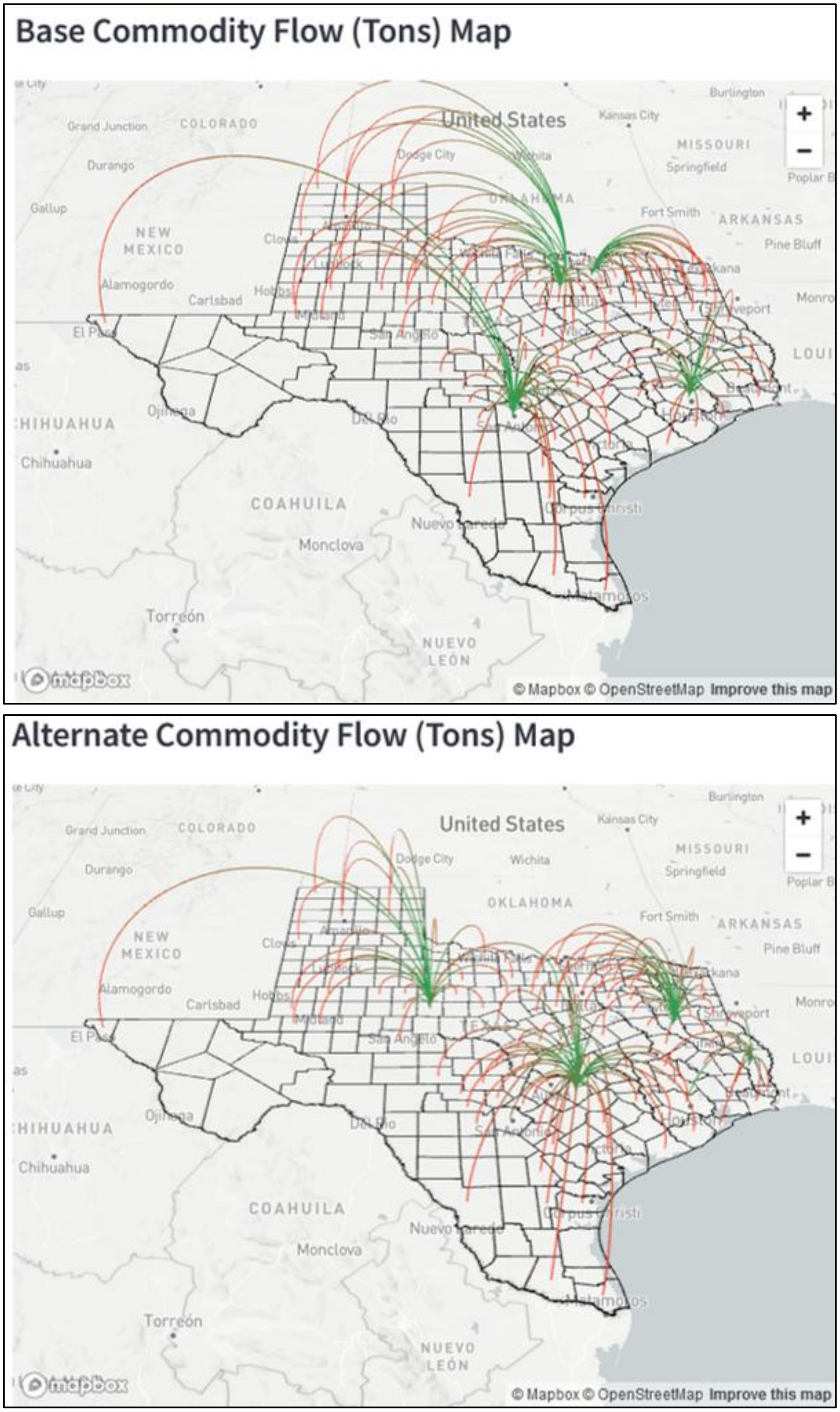
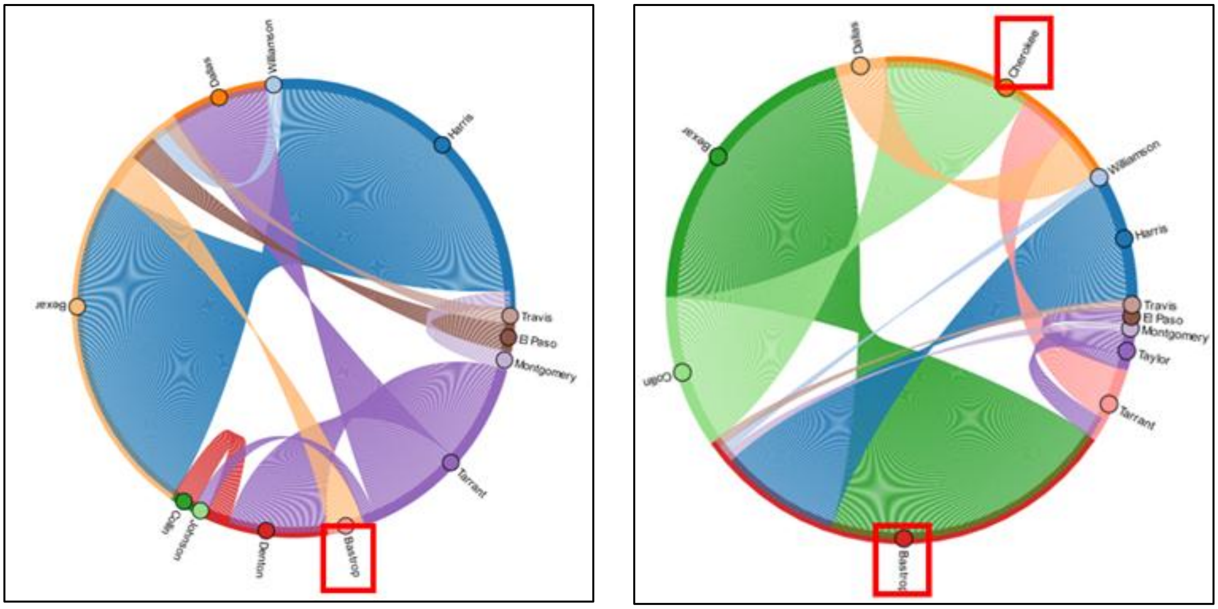


Figure F-19. Screenshots of Base Year and Transshipment Scenario *Flow Report*—Map.



(a) Base Scenario–Direct Flows: Top County OD Pairs

(b) Alternate Scenario–Warehousing Flows: Top County OD Pairs

Figure F-20. Screenshot of Base Year and Transshipment Scenario *Flow Report*—Chord Diagram.

NETWORK CLOSURE SCENARIO

Function

The Network Closure Scenario in the TFFM app is a statewide static traffic assignment function that utilizes the Transearch® Highway network. The trip-based network assignment uses the OD demand matrix structure based on the 254 counties in Texas. The traffic network assignment contains average daily auto vehicle demand from the Texas Statewide Analysis Model that is considered *background* traffic. The commercial truck demand for each scenario flows from the upstream scenario tools described previously. Each industry flow that is utilized from the previous upstream scenario tools is converted to an OD-based truck flow, and each industry flow is represented as a separate class of traffic assignment demand. The open-source modeling package, AequilibraE, is used as the multi-class equilibrium traffic assignment model. The Network Closure Scenario function assesses the network flow changes from the base network equilibrium run to a network closure of roadway links defined by the user. The user selects the network links and directions to be closed on an interactive map. The user is advised to enter a unique scenario name that describes the scenario closure being modeled.

Input Form

Step 1: Build Network Closure Scenario

Select *Build Network Closure Scenario* from the left sidebar of the *Home* page (see ① in Figure F-21). Selecting this option opens the *Network Closure Scenario* page where the user can select the link(s) for a complete capacity closure.

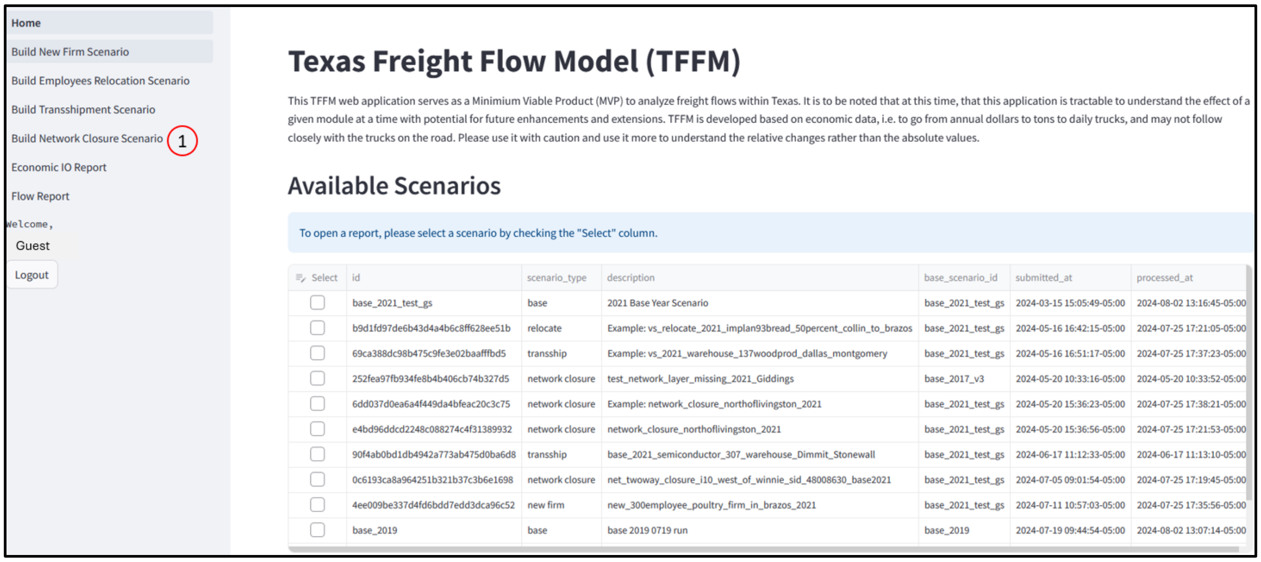


Figure F-21. Screenshot of *Build Network Closure Scenario* Initial Step.

Step 2: Select Base Scenario

From the base scenario drop-down menu (see ② in Figure F-22), choose a base scenario upon which the Network Closure Scenario will be applied.

Step 3: Select Closure Scenario Link(s)

On the map, individually select the link(s) to be closed in the scenario. When hovering over a link, a small window opens next to the mouse cursor. The window contains the segment ID, starting node, and end node for the link under the mouse cursor. Once a link is selected, the map display changes to show a green starting point and a red ending point, indicating the direction of the link (see ③ in Figure F-22). Also once a link is selected, the same link information from the hovering window is displayed in tabular format below the map (see ④ in Figure F-22).

Step 4: Select Link Direction

Select the link direction by checking or unchecking the *reverse* box in the right column of the link table (see ④ in Figure F-22). The user may also select the optional *Clear* button under the link table to clear all selected links in the table.

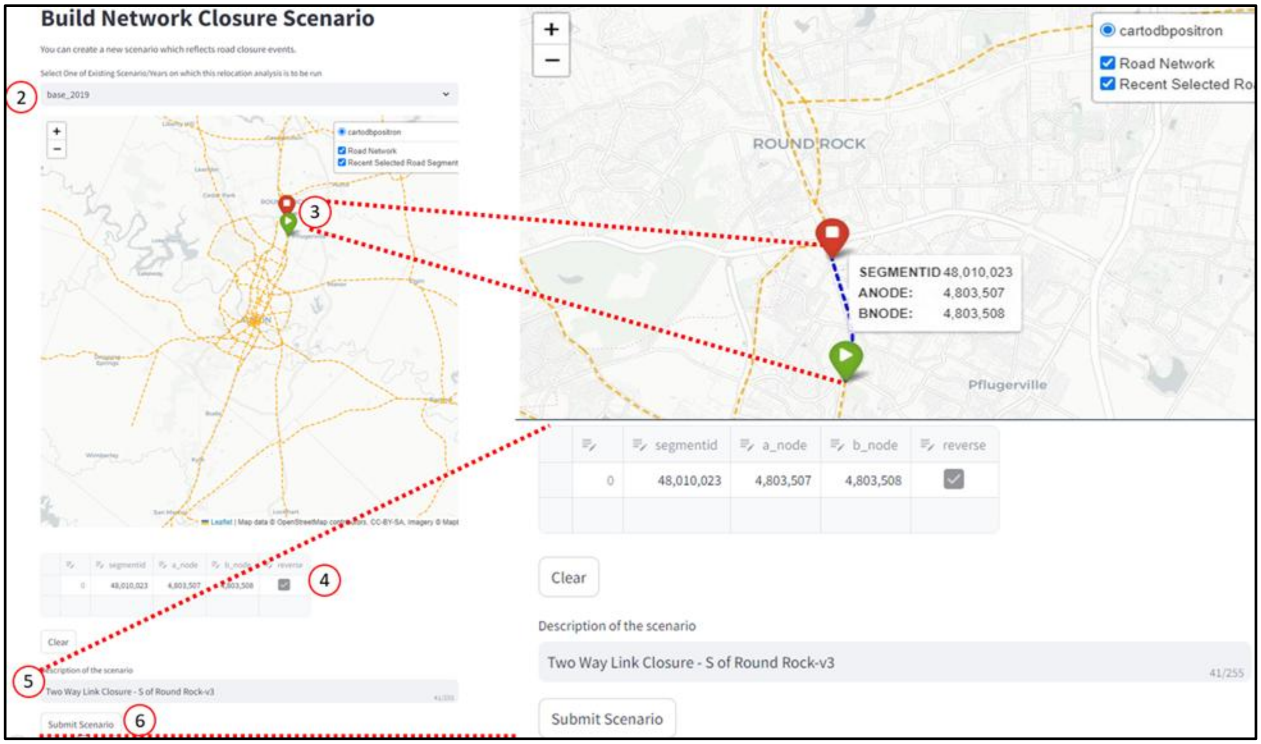


Figure F-22. Screenshot of *Build Network Closure Scenario* Steps.

Step 5: Create Scenario Description

Finally, enter a brief description/unique name for the Network Closure Scenario in the textbox field (see ⑤ in Figure F-22). This description helps identify and locate the scenario on the *Home* page once the report is ready for viewing.

Step 6: Submit Scenario

After completing steps 1-5, click the *Submit Scenario* button (see ⑥ in Figure F-22). The system will then run a static traffic assignment of the Network Closure Scenario created. This process takes approximately 1–3 minutes in the cloud-based TFFM backend. The analyst is subsequently notified that the analysis is complete through the app.

Results and Reporting

Once the Network Closure Scenario has completed its run, it will appear as an option in the list of *Available Scenarios* on the *Home* page. Unlike the previous scenarios, an additional report—a *Network Closure Report*—is available to summarize results. The steps to access this report and associated visualizations are discussed in the remainder of this section, using Figure F-23 as a reference.

Step 1: Go to Home Page

Access the *Home* page by default when logging into the TFFM app or by clicking the navigation link in the left sidebar of the *Home* page (see ① in Figure F-23) if already logged into the app.

Step 2: Select Scenario

To select the example scenario from all scenarios listed under *Available Scenarios*, click the check box next to the appropriate *id* (see ② in Figure F-23). The user should select a scenario categorized as *network closure* under *scenario_type* on this page.

Step 3: Select Report Type

Select *Network Closure* as the type of report from the drop-down menu (see ③ in Figure F-23).

Step 4: Open Report

Next, click the *Open Report* button (see ④ in Figure F-23) to generate a report. For this example, the user is directed to the *Network Closure Report* page.

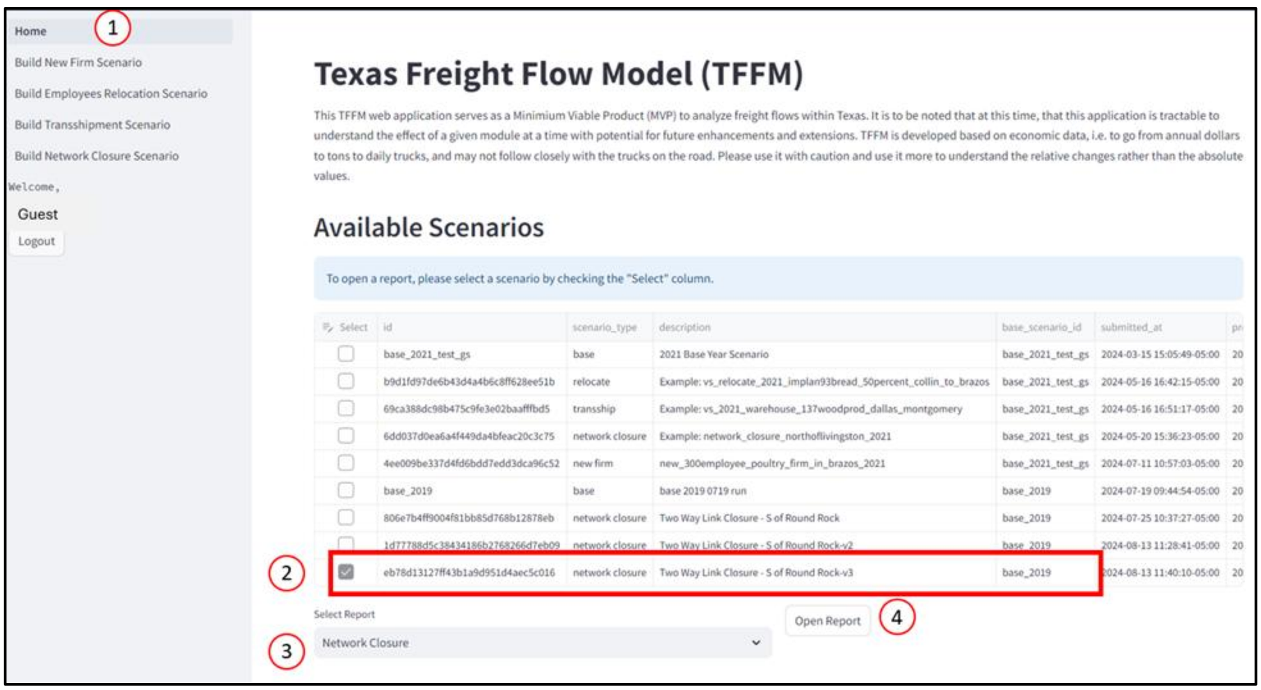


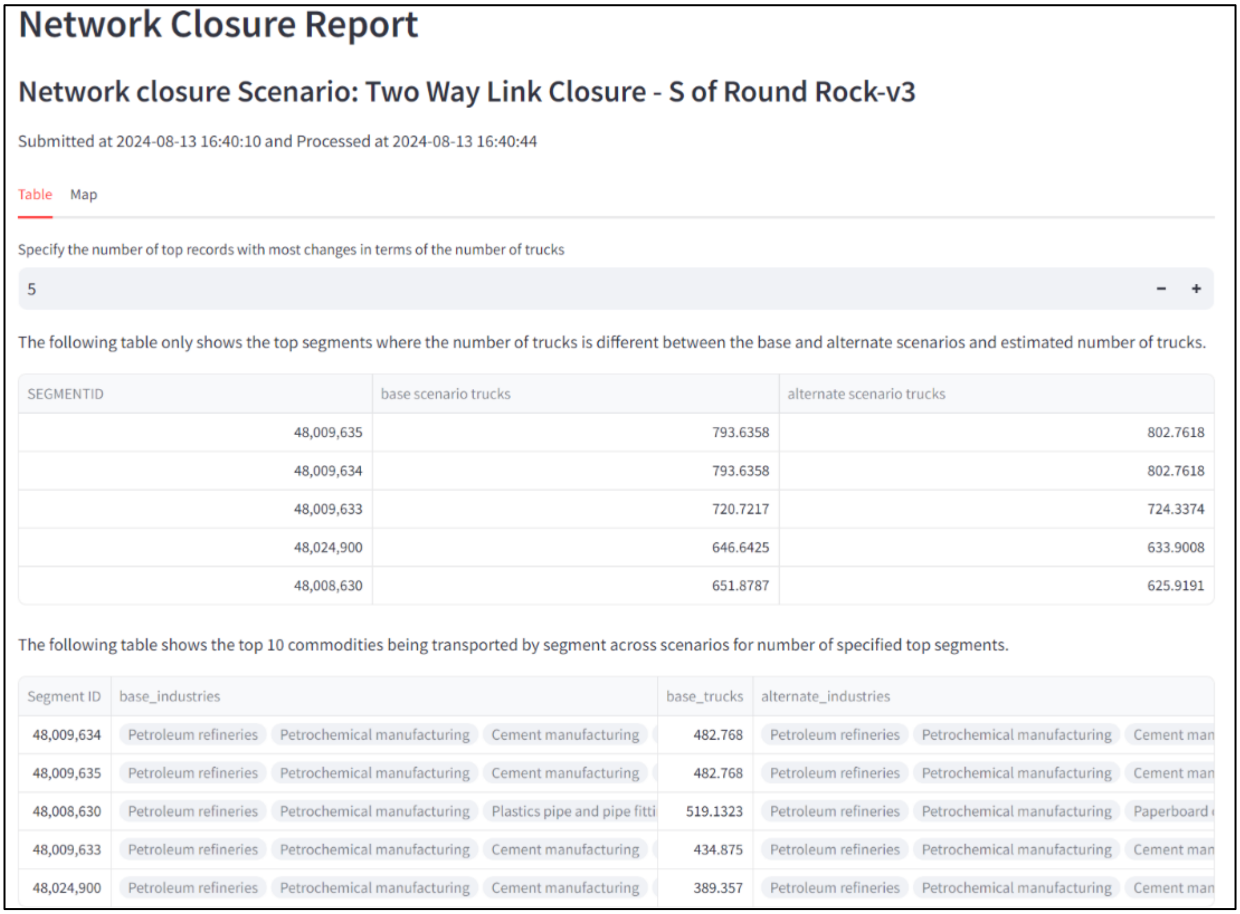
Figure F-23. Screenshot of *Network Closure Scenario Report* Selection Steps.

Network Closure Report

The *Network Closure Report* page compares base year and the Network Closure Scenario commodity flows. The user can view the results in tabular or map-based formats by selecting the *Table* or *Map* tabs (Figure F-24 and Figure F-25, respectively).

The tabular results in Figure F-24 detail the top-ranking numerical differences in flows between the two scenarios (base year and Network Closure Scenario). The user can specify the number of top-ranking records (e.g., top 20 or top 25) to display in the table.

The map-based results in Figure F-25 compare the base year and the Network Closure Scenario side-by-side. A color scale describes the number of trucks on the network links. The red square on each map indicates the location of the network closure. The impacts of the Network Closure Scenario can be observed by comparing the color gradient differences between the two maps.



Network Closure Report

Network closure Scenario: Two Way Link Closure - S of Round Rock-v3

Submitted at 2024-08-13 16:40:10 and Processed at 2024-08-13 16:40:44

Table Map

Specify the number of top records with most changes in terms of the number of trucks

5 − +

The following table only shows the top segments where the number of trucks is different between the base and alternate scenarios and estimated number of trucks.

SEGMENTID	base scenario trucks	alternate scenario trucks
48,009,635	793.6358	802.7618
48,009,634	793.6358	802.7618
48,009,633	720.7217	724.3374
48,024,900	646.6425	633.9008
48,008,630	651.8787	625.9191

The following table shows the top 10 commodities being transported by segment across scenarios for number of specified top segments.

Segment ID	base_industries	base_trucks	alternate_industries
48,009,634	Petroleum refineries, Petrochemical manufacturing, Cement manufacturing	482.768	Petroleum refineries, Petrochemical manufacturing, Cement man
48,009,635	Petroleum refineries, Petrochemical manufacturing, Cement manufacturing	482.768	Petroleum refineries, Petrochemical manufacturing, Cement man
48,008,630	Petroleum refineries, Petrochemical manufacturing, Plastics pipe and pipe fitti	519.1323	Petroleum refineries, Petrochemical manufacturing, Paperboard
48,009,633	Petroleum refineries, Petrochemical manufacturing, Cement manufacturing	434.875	Petroleum refineries, Petrochemical manufacturing, Cement man
48,024,900	Petroleum refineries, Petrochemical manufacturing, Cement manufacturing	389.357	Petroleum refineries, Petrochemical manufacturing, Cement man

Figure F-24. Screenshot of *Network Closure Report*—Table.

Figure F-25. Screenshots of *Network Closure Report*—Map.