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CENTER FOR TRANSPORTATION RESEARCH

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Commodity-based Approach for Evaluating the Value of Freight Moving on Texas' Roadway Network

C. Michael Walton
Nan Jiang
Rydell Walthall
Kevin Savage
Pavle Bujanovic
Dan Seedah
Zuocheng Wang
Jia Li
Katie Kam
Michael Murphy
Rob Harrison

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<tr><td colspan="5">16. Abstract
The researchers took a commodity-based approach to evaluate the value of a list of selected commodities moved on the Texas freight network. This approach takes advantage of commodity-specific data sources and modeling processes. It provides a unique way of performing commodity flow estimation and offers more disaggregated modeling results. The estimated value of commodities can be used to support infrastructure investment decision-making. The researchers also evaluated the impact of seasonal variation and congestion on commodity flow movements.</td></tr>
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Center for Transportation Research
The University of Texas at Austin
1616 Guadalupe, Suite 4.202
Austin, TX 78701

http://ctr.utexas.edu/

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Project Engineer: C. Michael Walton
Professional Engineer License State and Number: Texas No. 46293
P. E. Designation: Research Supervisor

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Table of Contents

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List of Terms

CFS	Commodity Flow Survey
EIA	Energy Information Administration
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
FIDO	Forest Inventory Data Online
FSIS	Food Safety and Inspection Service
GIPSA	Grain Inspection, Packers, and Stockyards Administration
GIS	geographic information system
GVWR	gross vehicle weight restriction
MPO	metropolitan planning organization
MRIO	multi-regional input-output
MSAU	Meat Safety Assurance Unit
NAICS	North American Industry Classification System
NASS	National Agricultural Statistics Service
OD	origin-destination
SAM	Statewide Analysis Model
SCAG	Southern California Association of Governments
STB	Surface Transportation Board
STCC	Standard Transportation Commodity Code
TAHC	Texas Animal Health Commission
TAZ	traffic analysis zone
TDA	Texas Department of Agriculture
TDMS	Texas Data Management System
TLMA	Texas Livestock Marketing Association
TWC	Texas Workforce Commission
TxDMV	Texas Department of Motor Vehicles
TxDOT	Texas Department of Transportation
USDA	US Department of Agriculture
VIUS	Vehicle Inventory and Use Survey

Chapter 1. Introduction

1.1 Background

In recent years, state transportation agencies have been encouraged to incorporate freight into their statewide transportation planning program, as highlighted by the Moving Ahead for Progress in the 21st Century Act (MAP-21). MAP-21 includes a number of provisions to improve the condition and performance of the national freight network. The Act (FHWA, 2012) requires state Departments of Transportation to direct resources toward improved movement of freight on highways through a number of initiatives, such as:

- Assessing the condition and performance of the national freight network,
- Identifying bottleneck segments,
- Forecasting freight volumes,
- Identifying major trade gateways and national freight corridors, and
- Assessing barriers to improved freight transportation performance.

Despite recognizing the need for improved freight planning, most states have limited planning tools to address goods movements and are lagging behind the freight industry in terms of technological and logistical advances (Hensher and Figliozzi 2007, Cambridge Systematics 2008).

Freight modeling is gradually moving from the traditional four-step modeling process to supply chain and logistics-based approaches, with the idea that such approaches can better capture rapid changes in the structure of the supply chain network and freight transportation systems.

However, both traditional four-step models and newer behavioral models face the challenge of lacking freight data. Readily accessible secondary or public data is only available in highly aggregate form and insufficient for model development. Primary data, which is collected by third-party firms, would be ideal but is proprietary in nature; clients are unwilling to share information because of the competitive nature of the business. Decision-makers are unwilling to participate in freight surveys (which can be costly for state agencies) for fear of disclosing sensitive information and losing their competitive edge (Samimi et al. 2009).

By acknowledging the challenge in freight data and the limitations of accurately modeling the supply chain, this study took a commodity-based approach after an extensive literature review on various methodologies. This approach takes advantage of commodity-specific data sources providing disaggregate data that are not readily available for all commodities. This approach also allows the research team to adjust specific modeling techniques based on the characteristics of each commodity. This methodology allows seamless incorporation of future updates to datasets and its individual modules can be further refined as new datasets become available.

1.2 Research Objectives

The major objective of this project was exploring the application of a commodity-based approach to evaluate freight value moved on Texas roadway systems. The research team obtained a better understanding of the applicability, advantages, and challenges associated with this approach during this research.

The research team obtained unique data sources for a list of selected commodities through online investigations and communication with industry representatives. This approach provides meaningful and useful data to support the research team's analysis about the commodities' movements.

With a thorough understanding of those commodities' movements in Texas, the research team was able to estimate the quantity of commodities moved from their origins to their destinations, as well as the routes, transportation modes, and vehicle types used. This information is useful to the Texas Department of Transportation (TxDOT) in two ways: the estimated link-level truck trips will ensure that policy-makers are adequately informed about the impact of truck freight movement on roadway conditions, while the link-level freight value can support infrastructure improvement decision-making.

The research team also sought to understand the impact of commodities' seasonal variation and congestion on commodity movements by evaluating changes in commodity production and consumption levels with time and using congested travel time in network analysis.

1.3 Organization of the Report

Chapter 2 provides an extensive literature review that summarizes typical freight modeling approaches and commodity flow models applied at different spatial levels. Also highlighted are data sources (including their limitations and benefits) and modeling approaches used from the local to international levels, including inputs and outputs as well as strengths and weakness. Lastly, several papers describing the modeling of a specific commodity are discussed.

Chapter 3 explains how and why the commodities studied in this project were selected and why the research team decided to not test certain commodities.

Chapter 4 relates the general procedure of commodity flow estimation taken by this study, while Chapter 5 demonstrates the process and results of applying each of these steps to each commodity. Chapter 5 uses this framework to discuss each commodity:

- Background
- Supply chain
- Datasets
- Commodity flow estimation
- Transportation
- Network analysis
- Compare with Transearch data
- Seasonal variation
- Daily truck trip assignment
- Summary

Following the discussion of each commodity, Chapter 6 describes comparing the estimation results with data from the Texas Data Management System (TDMS). TDMS data were not compared with each commodity because it does not contain any information about commodity type, so it was used to compare with the sum of all commodities. This chapter also elaborates how TDMS data was acquired and processed.

Chapter 7 shows one way of incorporating freight values into infrastructure decision-making to help rank bridges and pavement sections for improvement projects.

Finally, Chapter 8 summarizes this study's important findings and their potential value to TxDOT and other agencies.

Chapter 2. Literature Review

2.1 Freight Models in General

Freight modeling is a wide field, with many possibilities. Wigan & Southworth (2006) identified the following techniques seen in the literature for freight-related modeling:

- Linear and non-linear (e.g., logit) regression (to estimate traffic volume, origin-destination [OD] flows, and modal shares)
- Spatial interaction, neural network, and Box-Cox models of zone-to-zone (region-to-region) freight movements
- Commodity-based, inter-regional input-output models (typically used for trip distribution step, also known as freight vehicle flow matrix estimation)
- Microsimulation and agent-based models of individual freight vehicle movements
- Engineering cost-based, statistical (regression) based, mixed statistical-engineering cost-based, and hedonic freight pricing models
- Least cost-based single and multiple path freight traffic routing models
- Optimal facility location and combined site location-flow allocation models
- Network-based spatial price equilibrium models

Typically freight modeling requires a combination of the above techniques, with most doing some variation of the passenger four-step model that includes a step for converting commodity flow to vehicles. Each approach has its own strengths and weaknesses. For instance, input-output models capture industry relationships, but do not capture the following (Wigan & Southworth, 2006):

- Underlying behaviors that determine freight transport, or
- Causal relationships between businesses that explain choices in origins and destinations, mode, time of day, and routes.

Freight vehicle flow matrix estimation methods typically involve use of input-output models (for freight traffic generators and attractors) combined with a spatial interaction model (e.g., gravity model) to generate between region and between-industry flows. Alternatives to input-output models to produce truck trip matrices include use of:

- Land use-based traffic generation and attraction equations (which necessarily requires forecasting land use)
- ITS data to combine survey sample OD data and data from link traffic counts (combined with constrained mathematical programming models)

Current freight models generally do not capture carrier, broker, or shipper behaviors (Wigan & Southworth, 2006). The example given in that paper was of different market prices for local and export consumption; the amount used for local or export consumption will affect the model (truck versus rail). Econometric analysis of those types of changes is performed by private companies and departments of commerce but not necessarily integrated into freight models.

With that brief introduction to the wide variety of options for modeling freight, the following section focuses specifically on commodity flow models found in the literature relevant to this project.

2.2 Commodity Flow Models

The research team organized the literature review for the commodity flow models and the following presentation of findings by spatial application:

- City/substate
- US/national
- International

Even though the data sources may not be useful for Texas application, the review included an international scan of commodity flow models to find methodologies that could be used with US and Texas data.

For each modeling effort, the research team looked for answers to the following questions:

- What data is used? How was it acquired?
- Why were those data sources used?
- What are the limitations and benefits of the data, as cited in the paper?
- What is spatial level of data (city, county, region, state, etc.)?
- How is the data used in the model?
- How does the model estimate commodity flow and value on corridors?
- What are inputs to and outputs of model?
- What tools are used for the model (GIS [geographic information system], custom program, etc.)?
- How does model deal with multi-modalism?
- How do we see the model working for estimating freight value for Texas corridors?
- What are the strengths and weaknesses of the model?

2.2.1 City/Substate

Table 2.1 and Table 2.2 summarize four papers that examined commodity flow at the metropolitan or sub-state levels and were chosen because they highlight the approaches and data sources that could be used for commodity-flow models. A commonly seen approach to estimating commodity flow at the city and substate geographic level involves use of input/output modeling combined with socioeconomic data and/or Commodity Flow Survey (CFS) data.

The four example papers presented in the two tables were applied in non-Texas contexts, but could be applied to Texas areas. The most relevant model applied in a Texas context was developed under TxDOT Project 0-4430, Development of a Comprehensive Urban Commodity/Freight Movement Model for Texas (Texas Transportation Institute, 2006). For that project, estimation of commodities being shipped and received internally within the Houston-Galveston area used the estimates generated by the Texas Statewide Analysis Model (SAM) ('top-down') and by a model developed using data collected within the urban area ('bottom-up'). The bottom-up approach used the following data sources:

- National Transportation Atlas Database 2003
- Houston Intermodal Facility Inventory
- Houston Intermodal Facility Inventory GIS Database
- Development of Special Generator Trips for Ports
- Airline Statistics month reports published by the Houston Airport System
- Texas Pipeline Intermodal Connections GIS Database
- Texas Statewide Transportation Plan and Texas Rail System Plan
- CTR research report about containerized freight movement in Texas
- Final environmental impact statement for the Port of Houston Bayport and the Texas City Shoal Point Container Terminals
- New York Metropolitan Transportation Council reports providing details related to freight facilities in the New York metropolitan region.
- NCHRP funded synthesis on truck trip generation data
- FHA publication of the characteristics of urban freight systems

For trip generation, the urban model used commercial vehicle trip rates from the workplace survey and the commercial vehicle survey data to develop commodity rates that could be input into TRIPCAL5 (an add-on program for doing trip generation calculations). Trip distribution used the ATOM2 gravity model, and traffic assignment used the minimum time path, all or nothing approach.

Table 2.1: City/substate commodity flow models, part 1

Study	**Incorporating Freight Value into the Urban Mobility Report** (Wurfel, Bai, Huan, & Buhr, 2009)	**Estimating Commodity Inflows to a Sub-State Region Using Input-Output Data: Accuracy Tests Using the CFS** (Liu & Vilain, 2000)
Description	"The objective of this research is to develop a Kansas FAF [Freight Analysis Framework] for the Kansas City Metropolitan order to identify major freight corridors and connectors, and collect data that will be important in creating a long-range freight transportation plan."	"…describe a methodology to estimate current commodity inflows to a sub-state region using a supply-side, commodity-by-industry input-output model and commodity flow data for American states. Since the 1993 Commodity Flow Survey does not go below the state level, the estimation of commodity flows to a particular sub-state region in the United States has always proven difficult. By combining state-level commodity flow data with the supply-side commodity-by industry input-output model, an estimate of commodity flows to smaller regions can be carried out entirely based on the regional industrial structure."
Commodities studied	All commodities with a SCTG code	CFS commodities
Data used	2002 and 2007 FAF FHWA Vehicle Class Vehicle Inventory and Use Survey (VIUS) Kansas DOT truck count data Missouri DOT truck volume (GIS)	Input-output data 1993 CFS Regional data on employment or earnings by industry
Reason for data sources	Basis for developing a Kansas-specific FAF	The project required income data at the county-level, broken-down by industry.
Data limitations and benefits	The paper had to make assumptions converting commodity tonnage to trucks.	
Spatial resolution	Major metro areas and foreign trade zones	County level
Use of data	FAF used to find top commodities and create Kansas FAF. VIUS used to convert tonnage to trucks. Truck count data used to determine through trucks.	Use a regional input-output model to define the proportion of various commodities used by various industries in the region. Then, apply the proportions to the existing state-level commodity data from the 1993 CFS.

Study	**Incorporating Freight Value into the Urban Mobility Report** (Wurfel, Bai, Huan, & Buhr, 2009)	**Estimating Commodity Inflows to a Sub-State Region Using Input-Output Data: Accuracy Tests Using the CFS** (Liu & Vilain, 2000)
Methods used	Converted commodity tonnage to number of trucks (assuming all trucks are 5 axles/class 5). Through trucks calculated by subtracting from total truck counts the sum of the number of trucks into Kansas City and the number of trucks out of Kansas City. Through trucks assigned only to major highways.	
Model inputs and outputs	Model inputs include the 2002 and 2007 FAF and truck count data, and model outputs include estimates of tonnage and value of goods shipped by type of commodity and mode of transportation.	Model outputs sub-state commodity inflows.
Tools used	Kansas FAF website with database query	GIS
Modes	Highway, railroad, air, and water	n/a (commodities, not modes)
Applicability for TX	The Kansas FAF could be adapted to create a Texas FAF.	Yes, can be applied to Texas
Model strengths and weaknesses	The model is simple and easy to calculate, but the resolution depends on the data, and the final model uses an adjustment factor based on known commodity values for some particular regions, and extrapolating the correction to the rest of the model.	The methodology takes in to account the possibility that the input needs of a regional industry are met, in whole or in part, by regional suppliers. Also the model starts with the *observed* state-level commodity inflows as a starting point. A major weakness of the model is that the estimate errors of individual commodities were significantly greater than the estimates for total freight inflows.

Table 2.2: City/substate commodity flow models, part 2

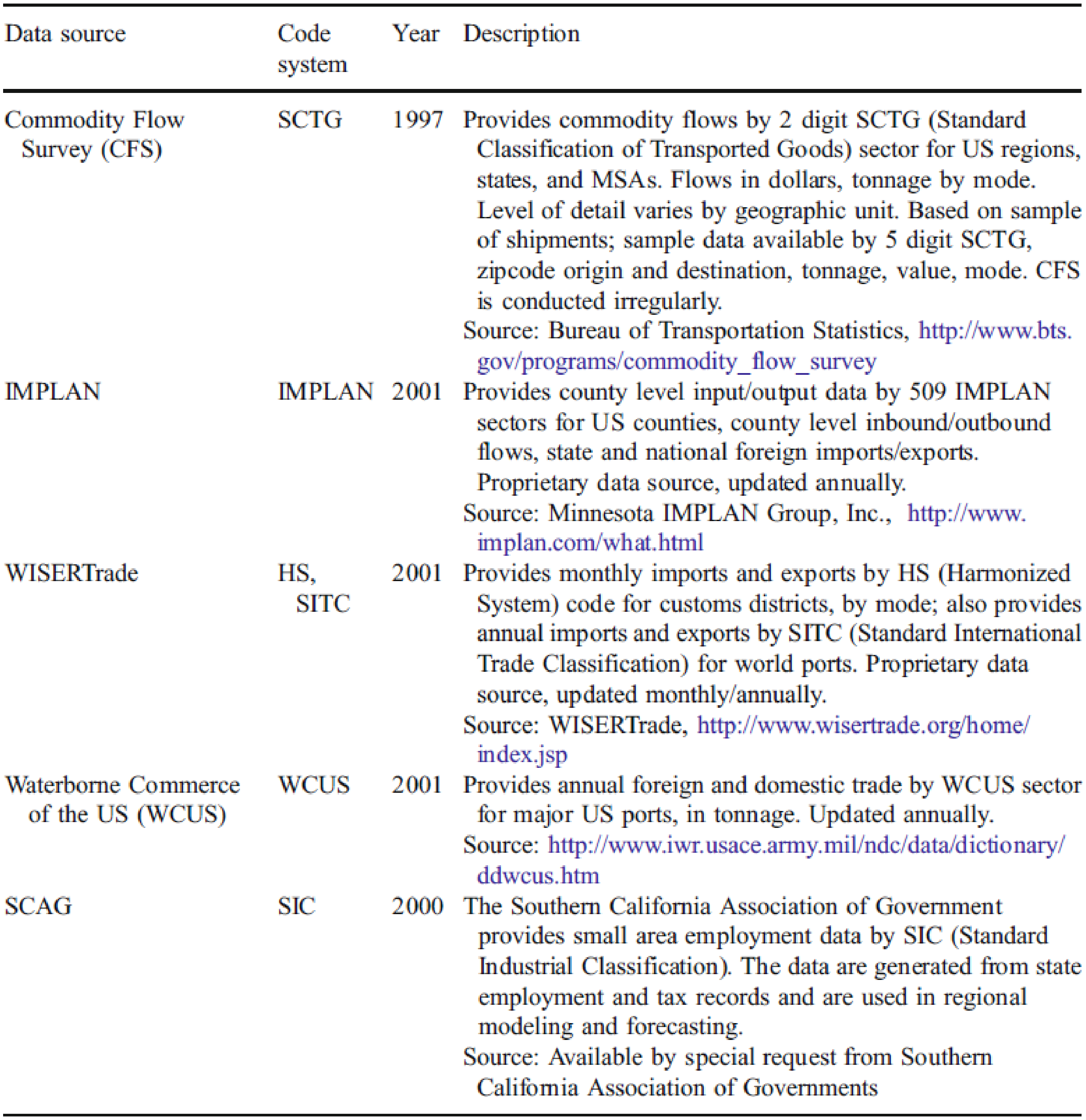
Study	**Developing a Commodity Flow Database from Transearch Data** (Ahanotu, Fischer, & Louch, 2003)	**Estimating Freight Flows for Metropolitan Area Highway Networks Using Secondary Data Sources** (Giuliano, Gordon, Pan, Park, & Wang, 2010)
Description	"This paper discusses the strengths and weaknesses of the Transearch data, outlines a methodology for refining and verifying important Transearch data elements, and describes a process for improving commodity flow databases from comparing the Transearch data to other available freight data sources." The primary contribution is in how to supplement Transearch for underrepresented commodities. Applied to Portland, OR	The paper presents "a method for estimating intra-metropolitan freight flows on a highway network. The work is part of a larger project aimed at developing an automated, integrated system for freight flow analysis and planning. To overcome the limitations of current estimation methods for commodity flows, we use reliable secondary sources, including small-area employment data, and derive estimates in a plausible way by means of a computational workflow. When available, we extract the data automatically from online sources, so that estimations can be continuously updated. Using widely available data sources allows for transferability. In this paper we provide an overview of our modeling approach and the major data sources used. We apply the model using data from the Los Angeles region, and compare our traffic assignment results with available screenline counts."
Commodities studied	Commodities under the Standard Transportation Commodity Code (STCC) system except for farm products (excluding fresh fruit and vegetables), waste and scrap materials, non-metallic minerals (e.g., stone and aggregate), forest products, fresh fish and marine products, and tobacco products.	
Data used	Transearch, supplemented with: State Department of Agriculture data	IMPLAN Input-output data 1997 CFS WISERTrade

Study	**Developing a Commodity Flow Database from Transearch Data** (Ahanotu, Fischer, & Louch, 2003)	**Estimating Freight Flows for Metropolitan Area Highway Networks Using Secondary Data Sources** (Giuliano, Gordon, Pan, Park, & Wang, 2010)
	Aerial photos, zoning permits, zoning district data Oregon Department of Geology and Mineral Industries (county level) State environmental protection agencies (for waste and scrap) US Department of Energy's Energy Information Administration (and interviews with energy production facilities to find truck/pipeline split) Input-output data Portland, OR's freight facility databased (maintained by Metro), Dun & Bradstreet, or Info USA for freight facilities Wholesale receipts data from the Bureau of the Census (for secondary flows, at intermediate stops), converted from dollars to tonnage CFS (to refine and validate Transearch) Local survey and count data (to compare results) Average payload per truck data can be generated from survey data, weigh-in-motion data, or census bureau vehicle inventory and use survey state data.	Waterborne Commerce of the US (WCUS) SCAG (Southern California Association of Governments) screenline traffic counts and model results See Table 2.3.
Reason for data sources	Transearch used because most commonly used data source for freight flow data with OD information. Input-output data to determine origins and destinations of commodities.	Widely available and to use an input-output approach to commodity-flow modelling

Study	**Developing a Commodity Flow Database from Transearch Data** (Ahanotu, Fischer, & Louch, 2003)	**Estimating Freight Flows for Metropolitan Area Highway Networks Using Secondary Data Sources** (Giuliano, Gordon, Pan, Park, & Wang, 2010)
Data limitations and benefits	Data for nonmanufacturing and secondary flow (emerging from intermediate points) commodities in Transearch still underrepresented.	Use of multiple data sources provides wealth of info but requires reconciling differences
Spatial resolution	Metropolitan and county level	Metropolitan and county level
Use of data	The paper explains way on to improve estimation of commodity flow for the underrepresented commodities.	Use widely available data sources to estimate link-specific truck freight flow
Methods used	Find alternative data sources for specific commodities.	1. Estimate commodity-specific interregional and international trip attractions and trip productions for those locations where airports, seaports, rail yards, or regional highway entry-exit points are located. 2. Utilize a regional input–output transactions table to estimate intraregional commodity-specific trip attractions and trip productions at the level of small area units. 3. Create a regional commodity-specific OD matrices using estimates from steps (1) and (2). 4. Load the O–D matrices onto a regional highway network with known passenger flows. Refer to Figure 2.1 and Figure 2.2 for flowchart of process and data use
Model inputs and outputs	The paper is less about a model, and more about developing a more complete commodity flow database using Transearch as the base to build upon.	Inputs: See data sources Output: Link-specific truck freight flow
Tools used		SCAG transportation demand model

Study	**Developing a Commodity Flow Database from Transearch Data** (Ahanotu, Fischer, & Louch, 2003)	**Estimating Freight Flows for Metropolitan Area Highway Networks Using Secondary Data Sources** (Giuliano, Gordon, Pan, Park, & Wang, 2010)
Modes	All	Truck
Applicability for TX	This paper points out the issues with using Transearch data for certain commodities and proposes data and methods to estimate those underrepresented commodities, which will help any Texas modelling effort.	The data sources and methodology are transferable to Texas city applications, with local metropolitan planning organization (MPO) models used instead of SCAG models.
Model strengths and weaknesses	The methodology expands upon the Transearch data to create a more complete database for metropolitan level freight analysis. Requires consulting multiple data sources.	Model strengths: Uses widely available data that can be automatically updated Model weaknesses: Requires use of multiple data sources, with different classification systems, definitions, and frequency of updates.

Table 2.3: Major data sources for estimating freight flows for metropolitan area highway networks using secondary data sources (Giuliano, Gordon, Pan, Park, & Wang, 2010)



Data source	Code system	Year	Description
Commodity Flow Survey (CFS)	SCTG	1997	Provides commodity flows by 2 digit SCTG (Standard Classification of Transported Goods) sector for US regions, states, and MSAs. Flows in dollars, tonnage by mode. Level of detail varies by geographic unit. Based on sample of shipments; sample data available by 5 digit SCTG, zipcode origin and destination, tonnage, value, mode. CFS is conducted irregularly. Source: Bureau of Transportation Statistics, http://www.bts.gov/programs/commodity_flow_survey
IMPLAN	IMPLAN	2001	Provides county level input/output data by 509 IMPLAN sectors for US counties, county level inbound/outbound flows, state and national foreign imports/exports. Proprietary data source, updated annually. Source: Minnesota IMPLAN Group, Inc., http://www.implan.com/what.html
WISERTrade	HS, SITC	2001	Provides monthly imports and exports by HS (Harmonized System) code for customs districts, by mode; also provides annual imports and exports by SITC (Standard International Trade Classification) for world ports. Proprietary data source, updated monthly/annually. Source: WISERTrade, http://www.wisertrade.org/home/index.jsp
Waterborne Commerce of the US (WCUS)	WCUS	2001	Provides annual foreign and domestic trade by WCUS sector for major US ports, in tonnage. Updated annually. Source: http://www.iwr.usace.army.mil/ndc/data/dictionary/ddwcus.htm
SCAG	SIC	2000	The Southern California Association of Government provides small area employment data by SIC (Standard Industrial Classification). The data are generated from state employment and tax records and are used in regional modeling and forecasting. Source: Available by special request from Southern California Association of Governments

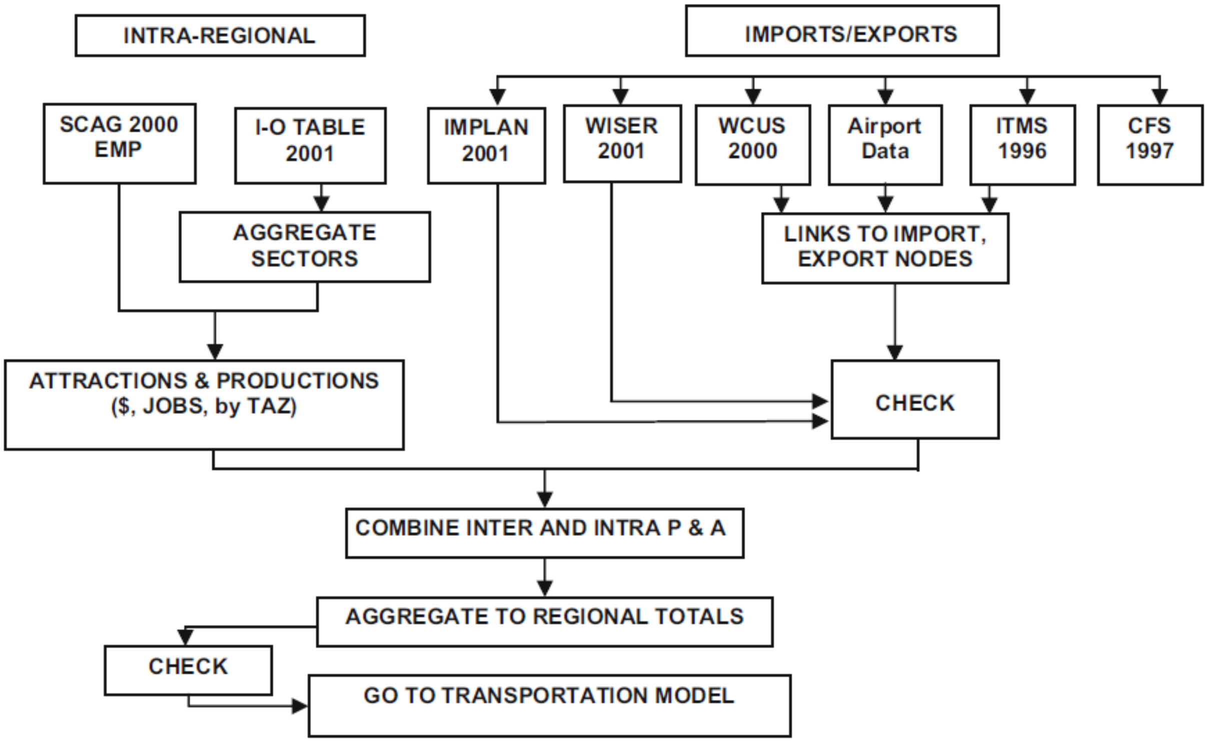


Figure 2.1: Data Process for Commodity Flow Model (Giuliano, Gordon, Pan, Park, & Wang, 2010)

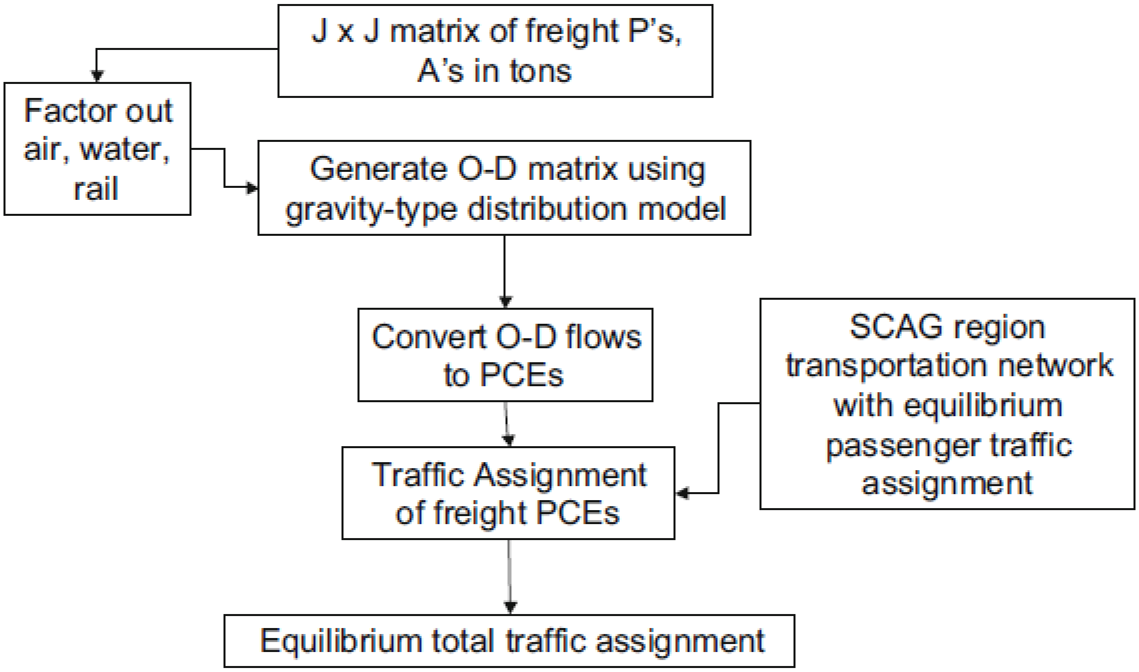


Figure 2.2: Commodity Flow Model (Giuliano, Gordon, Pan, Park, & Wang, 2010)

2.2.2 State/Regions

NCHRP 606: Forecasting Statewide Freight Toolkit (2008) provided a framework for preparing forecasts of freight transportation and documented several existing statewide freight transportation models. Additionally, Pearson et al. (2006) prepared a literature review of freight/commodity modeling practices in the final report for TxDOT Project 0-4430, Development of a Comprehensive Urban Commodity/Freight Movement Model for Texas.

Due to the number of papers and reports of state-level commodity flow estimation, and the direct applicability and relevance to this research project, the following tables (Tables 2.4 through 2.9) summarize several such models. Following the tables is more information about the state-level models, with full references given in this section.

Table 2.4: State commodity flow models part 1

Model	**Quick Response Freight Manual Final Report (QRFM)**	**Iowa Statewide Truck Forecasting Model**	**Kansas Statewide Model**
Client	N/A	Iowa DOT	Kansas DOT
Study Area	N/A	Iowa	Kansas
Year (Development or Update)	1991	1996	1992
Type of Model (Vehicle-Based or Commodity-Based)	Vehicle-based	Commodity-based	Commodity-based
Number of Commodities	N/A	2	5
Trip Generation	Apply default trip generation rates to employment categories and households	N/A	OD table collected within the state supplemented by surveys
Trip Distribution	Gravity Model	N/A	OD table collected within the state supplemented by surveys
Mode Choice	N/A	N/A	N/A
Assignment	Passenger Car Equivalence	N/A	All-or-nothing
Modes	Road	Road	Road

Table 2.5: State commodity flow models part 2

Model	**Kentucky Statewide Traffic Model**	**Massachusetts Truck Model**	**Michigan Statewide Truck Model**
Client	Kentucky Transportation Cabinet	Massachusetts DOT	Michigan DOT
Study Area	Kentucky	Massachusetts DOT	Michigan
Year (Development or Update)	1997	1998	1994
Type of Model (Vehicle-Based or Commodity-Based)	Commodity-based	Commodity-based	Vehicle-based
Number of Commodities	N/A	N/A; all commodities combined	N/A
Trip Generation	Population used to disaggregate for production/attraction	N/A	Two-state destination choice model used with region-to-region flows from benchmark input-output accounts
Trip Distribution	Gravity Model	OD matrix created from 1993 CFS	Two-state destination choice model used with region-to-region flows from benchmark input-output accounts
Mode Choice	N/A	N/A	N/A
Assignment	N/A	User equilibrium	All-or-nothing
Modes	Road	Road	Road

Table 2.6: State commodity flow models part 3

Model	**Statewide Freight Trip Forecasting Model for Nebraska**	**Texas Statewide Analysis Model**	**Wisconsin Statewide Freight Model**
Client	Nebraska DOT	TxDOT	Wisconsin DOT
Study Area	Nebraska	Texas	Wisconsin
Year (Development or Update)	2003	Late 1990s	1997
Type of Model (Vehicle-Based or Commodity-Based)	Commodity-based	Commodity-based	Vehicle-based
Number of Commodities	24	38 commodity groups aggregated into 10 categories	N/A
Trip Generation	Production: tonnages converted to truck trips. Attractions: Input-Output structure within MEPLAN	Regression analysis using demographic data variables; applied using TransCAD GISDK	Trip rates developed from OD surveys as a function of population
Trip Distribution	N/A	Doubly-constrained gravity model	Gravity Model
Mode Choice	N/A	Logit Model	N/A
Assignment	N/A	All-or-nothing	All-or-nothing
Modes	Road	Road	Road

Table 2.7: State commodity flow models part 4

Model	**Indiana Commodity Transport Model**	**Minnesota Trunk Highway 10 Truck Trip Forecasting Model**	**Heavy Truck Freight Model for Florida Ports**
Client	Indiana DOT	Minnesota DOT	Florida DOT
Study Area	Indiana	Trunk Highway 10	Florida Ports
Year (Development or Update)	1993	2002	1999
Type of Model (Vehicle-Based or Commodity-Based)	Commodity-based	Vehicle-based	Vehicle-based
Number of Commodities	19	N/A	N/A
Trip Generation	Regression Equations	Quick Response Freight Manual Trip Generation Equations	Time Series Models or Regression Models
Trip Distribution	Fully constrained gravity model or entropy model	N/A	N/A
Mode Choice	Modal split computer model (NEWMODE)	N/A	N/A
Assignment	All-or-nothing	N/A	N/A
Modes	9 single mode categories; 8 multimode categories	Road	Road

Table 2.8: State commodity flow models part 5

Model	**Ohio Interim Freight Model**	**New Jersey Statewide Model Truck Trip Table Update Project**	**Florida Intermodal Statewide Highway Freight Model (FISHFM)**
Client	Ohio DOT	New Jersey DOT	Florida DOT
Study Area	Ohio	New Jersey	Florida
Year (Development or Update)	2002	1999	2002
Type of Model (Vehicle-Based or Commodity-Based)	Commodity-based	Vehicle-based	Commodity-based
Number of Commodities	13; top truck commodities	N/A	14
Trip Generation	Within Transearch	Employment and/or other economic variables used to produce OD table	Transearch Regression Equations
Trip Distribution	Within Transearch	Employment and/or other economic variables used to produce OD table	Standard Gravity Model
Mode Choice	Market segmentation developed for Northern Ohio Rail Highway Corridor case study	N/A	Incremental Logit Model
Assignment	Fixed path routing method based on National Highway Network (NHN)	N/A	Assigned to highway network, major arterials and skeletal highway network outside Florida
Modes	Road (primary), rail, air, water	Road	Road (primary), rail, air, water

Table 2.9: State commodity flow models part 6

Model	**Cross-Cascades Corridor Analysis Project (Washington State)**	**Oregon Statewide Passenger and Freight Forecasting Model**	**Utah Statewide Freight Model**
Client	Washington State DOT	Oregon DOT	Utah DOT
Study Area	Cross-Cascades Corridor: Seattle to Spokane	Oregon	Utah
Year (Development or Update)	2001	1999	2013
Type of Model (Vehicle-Based or Commodity-Based)	Commodity-based	Commodity-based	Commodity-based
Number of Commodities	N/A	N/A	50 Transearch STCC2 commodity groups collapsed into 12 categories
Trip Generation	Input-Output Structure within MEPLAN	Within TRANUS	Regression Equations
Trip Distribution	Input-Output Structure within MEPLAN	N/A	Separate long-haul and short-haul distribution; use of QRFM procedure
Mode Choice	Calculated based on monetary values of time, distance and cost	Simultaneous mode split and assignment as loading to multimodal network	Based on Transearch Data
Assignment	Calculated based on monetary values of time, distance, and cost	Simultaneous mode split and assignment as loading to multimodal network	Assignment to highway network
Modes	Road, rail, air	Rail, rail, air, water	Road

Since state-level applications are most relevant to this project, the following lists state-level modeling efforts. For ease of reference, the literature source is given in bold, followed by highlighted findings.

Cambridge Systematics, National Cooperative Highway Research Program, American Association of State Highway, & Transportation Officials. (2008). Forecasting Statewide Freight Toolkit (Vol. 606). Transportation Research Board.

Minnesota Trunk Highway 10 Truck Trip Forecasting Model

- Data sources:
    - History truck traffic data from 1992 to 1999
    - Socioeconomic data from the Minnesota Department of Economic Security
    - Labor projections from the Minnesota Department of Planning
- Methodology for the TH 10 corridor relied primarily on spreadsheet calculations. Business Map by ESRI and HarrisInfo database of manufacturers was also used.
- Trip Generation: model used the Quick Response Freight Manual trip generation equations.
- No trip distribution (growth factors developed for individual sections of the corridor).
- No mode split.
- No traffic assignment.

Heavy Truck Freight Model for Florida Ports

- Data sources:
    - Terminal company's truck data
    - Gate pass data
    - Videotape counts
    - Vessel movements
    - Gantry crane activities
    - Trailer/container activity reports
    - Statistical monthly trailer/container performance reports
- Trip Generation: developed using time series models or regression models.
- No trip distribution, mode split, or traffic assignment.

Ohio Interim Freight Model

- Model includes top 13 truck commodities.
- Data sources:
    - 1998 Transearch database
    - Forecasts of Ohio's economy from DRI-WEFA

  - 1993 CFS
  - Vehicle Inventory and Use Survey (VIUS)
- Developed using software such as ArcView GIS, Microsoft Access, Microsoft Excel, and the Highway Economic Requirements System (HERS).
- Model used Transearch OD data for trip generation and distribution.
- Base year split among modes from Transearch was assumed to be constant into the future.
  - Mode split by market segmentation developed for Northern Ohio Rail Highway Corridor case study.
- Assignment process used fixed path routing method based on National Highway Network (NHN).
- Transearch does not account diverting traffic onto multiple routes nor can it distinguish shortest paths from points not at county centers.

New Jersey Statewide Model Truck Trip Table Update Project

- Data obtained from NJDOT, NYDOT, DDOT, DVRPC, PANYNJ.
- Developed using TRANPLAN software and custom FORTRAN scripts.
- No commodity groups identified.
- OD table produced by applying truck trip generation and distribution steps to existing and forecast employment or other economic variables.

Florida Intermodal Statewide Highway Freight Model (FISHFM)

- Data sources:
  - Population data from 1998 US Census of Population, Florida MPOs, local planning departments, and FSUTMS data (ZDATA1) sets.
  - Employment data from Regional Economic Information Systems, County Business Patterns, SIC employees by traffic analysis zone (TAZ), Florida MPOs, local planning departments, FSTUMS data (ZDATA2) sets, and the Florida Department of Labor.
  - Transearch
  - CFS
  - US Census Bureau's VIUS
  - 1999 AADT Report for Florida and Truck Weight Study Data
- 14 commodity groups identified.
- Run using TRANPLAN software and FSUTMS scripts. Two FORTAN programs were developed for model, FGEN and FMODESP.

- Trip generation based on regression production and attraction equations within Transearch.
- Trip distribution: standard gravity model. Trip lengths calculated using Transearch.
- Mode split: incremental logit model.
- Assigned to highway network, including Florida Intrastate Highway System, major arterials, collectors, and skeletal network developed from the National Highway Planning Network outside Florida.

Cross-Cascades Corridor Analysis Project (Washington State)

- Spatial Input-Output model.
- Data sources:
    - 1997 Reebie Transearch OD flows (tons);
    - 1997 US CFS Washington State Internal-External (I-E)/Interstate (I-I) tons and trip lengths;
    - 1995 Eastern Washington Intermodal Transportation Study (EWITS) Internal-External Truck tons;
    - 1996 Washington Freight Rail Study through E-E/E-I tons;
    - Washington Airport Activity Statistics Cargo tonnage enplaned/deplaned;
    - Washington State Population Survey;
    - County-level 1998 employment data.
- MEPLAN software used to run model.
- Trip generation and distribution: input-output structure using MEPLAN.
- Mode and route choice: calculated based on monetary values of time, distance, and cost.

Oregon Statewide Passenger and Freight Forecasting Model

- Economic class of model designed for forecasting both passenger and freight movements.
- Model estimates yearly flow of commodities among TAZs, which it converts to daily weekday freight movements.
- Developed from TRANUS, an integrated land use and transportation model applied at urban or regional scale.
- Trip generation accomplished within TRANUS.
- No trip distribution.
- Mode split and assignment simultaneous as loading to multimodal network.

Yang, C. H., Chow, J. Y., & Regan, A. (2009). State of the art of freight forecasting modeling: lessons learned and the road ahead. In *Transportation Research Board 88th Annual Meeting* (No. 09-3384).

- References NCHRP 606.
- Texas, Pennsylvania, Iowa, and Florida have developed their own four-step process commodity models.
- Oregon developed a statewide model based on an economic and land use behavioral model.
- Activity-based modeling is meant to overcome several deficiencies in practice including: crude conversions of commodity flows to vehicular flows, poor explanation for empty vehicles, and inability of aggregate models to forecast impacts due to changes in logistic structures.
- References Sivakumar and Bhat (2002) for distributing commodity flows.
- Logistics models have not been applied by any US state since private firm supply chain costs and operating behaviors are unavailable.
- Applies class D model (four-step commodity model) to California, replacing gravity model with fractional split model by Sivakumar and Bhat or the tour-based model by Wang and Holguin-Veras.
- California has several major metropolitan areas, so a vehicle-based truck touring model should be implemented.
- For a statewide model, it can be argues that such visibility is best left to the metropolitan planning agencies.

Shabani, K., Worthen, C., Outwater, M., & Steinvorth, W. (2014). Development of a Statewide Freight Trip Forecasting Model for Utah. In *Transportation Research Board 93rd Annual Meeting* (No. 14-3859).

- Uses inter-regional commodity flow model for longer trips and an intra-regional commercial vehicle model for shorter trips.
    - Separate commercial vehicle model is required since many short-haul truck movements are not captured in Transearch.
- Data Sources:
    - Transearch
    - FAF3
    - VIUS
    - Utah Geological Survey (for case studies)
    - Utah Division of Oil, Gas & Mining (for case studies)
    - Energy Information Association (for case studies)

- 50 Transearch commodity groups collapsed into 12 categories.
- Long-haul trip generation production and attraction rates estimated through linear regression using commodity tonnages and employment data.
- Short-haul generation rates based on the Federal Highway Administration's (FHWA) commercial vehicle research. Rates estimated from average per capita fleet size and vehicle trip rates from several US urban areas.
- Long-haul commodities distributed nationally to BEA zones outside Utah and TAZs inside UTAH, then trimmed to statewide model space using a sub-area extraction.
- Short-haul trips distributed on the statewide scale only.
- Mode share model based on Transearch data.
- Empty trucks estimated from VIUS data.
- Case studies for coal and crude oil in Utah.
- Transearch data had incorrect distribution and mode shares and incorrect tonnage for both coal and crude oil categories.

Proussaloglou, K., Popuri, Y., Tempesta, D., Kasturirangan, K., & Cipra, D. (2015). Wisconsin passenger and freight statewide model: case study in statewide model validation. *Transportation Research Record: Journal of the Transportation Research Board*.

- Four-step freight model used commodity flow data to develop trip generation and trip distribution models for 25 commodities.
- Estimates of observed truck traffic counts used to validate the model truck trip table.
- Trip generation: production rates related the tonnage generated for each commodity to categories of SIC-2 employment. Attraction rates also developed.
- Trip distribution: gravity mode proposed by Black. FAF provided average trip lengths and distributions of trip lengths to validate results from gravity model.
- Outputs were aggregated to the county level and compared with Transearch.
- Commodity flows converted to truck movements using factors from VIUS.

Casavant, K., Sorenson, P., & Chase, B. (2002). *Methodology for Determining Washington State Value-added of Freight Moved in Washington Corridors* (No. WA-RD 540.1,).

- Information needed is an estimate of the tonnage being moved through a corridor or region.
- IMPLAN provides value-added coefficients for each industry in its direct requirements table.

Duanmu, J., Foytik, P., Khattak, A., & Robinson, R. (2012). Distribution Analysis of Freight Transportation with Gravity Model and Genetic Algorithm. *Transportation Research Record: Journal of the Transportation Research Board*, (2269), 1-10.

- Centroids for gravity models should be places where most business units are located, not geographic center.
- Gravity model must be generated for different business categories.
- Trip rate per employee decreases as the employee population increases.
- Commodity-based, county-level gravity model was constructed to 31 counties in southeastern VA.
- Gravity model predicted directed flows between OD pairs using commodity tonnage.
- A Genetic Algorithm was used to determine the best combination of parameters to minimize the error between output and observed values.
- Data compared with Transearch data.
- Freight flow of products with a few providers and consumers cannot use a gravity model.
- Gamma function that uses travel time as the deterrence factor generates better approximation for gravity model than exponential expression.

Jin, T. G., Saito, M., & Schultz, G. G. (2012). Development of a Statewide Commodity Flow Distribution Model Using Composite Friction Factors. *Procedia-Social and Behavioral Sciences, 43*, 406-417.

- Uses enhanced gravity model with composite friction factors.
- Data sources:
    - 2002 CFS
    - FAF2
    - Official website of the state of Utah
    - 2002 County Business Patterns (from FAF)
- Need to calibrate parameter values of the four factors used in the model.
- No data available to validate mode because neither CFS nor FAF provided county-level commodity flow data.

Bujanda, A., Villa, J., & Williams, J. (2012). Development of Statewide Freight Flow Assignment with Freight Analysis Framework: Learning from Case Study on International Trade Corridors in Texas. *Transportation Research Record: Journal of the Transportation Research Board*, (2285), 155-166.

- Uses Freight Analysis Framework 3 (FAF3).

- Texas's international trade corridors used as case study.
- Data sources:
    - FAF3
    - Bureau of Transportation and Statistics (BTS) data for ports of entry (POE)
    - US Army Corps of Engineers International Waterborne Commerce
- ArcGIS and TransCAD both used.
- Assignment was accomplished using get directions function in Google Maps.
- Problems:
    - FAF3 data is very aggregated.

Sivakumar, A., & Bhat, C. (2002). Fractional split-distribution model for statewide commodity-flow analysis. *Transportation Research Record: Journal of the Transportation Research Board,* (1790), 80-88.

- Data sources:
    - Reebie Transearch Freight Database
    - County Business Patterns
    - US Census Bureau Population projections
    - Regional Economic Information System (REIS) database compiled by the US Bureau of Economic Analysis
    - TransCAD geographic maps and datasets
- Model is a polychotomous extension of the binary fractional split model proposed by Papke and Wooldridge (1996)
- A multinomial logit function form is used in the fractional split model.
- 50 commodity types organized into 7 commodity groups; three commodity groups chosen for study:
    - Agriculture and Related Products
    - Construction Materials
    - Food and Related Products
- Source of error: Reebie database does not provide information on flows between Texas and Mexico, only flows from/to Texas as a whole.

Sorratini, J. A. (2000). Estimating statewide truck trips using commodity flows and input-output coefficients. *Journal of Transportation and Statistics, 3*(1), 53-67.

- Data sources:

    - 1993 CFS
    - Transearch
    - Input-Output Coefficients
    - County Business Patterns
- 28 economic sectors (commodity groups) studied
- Freight Attractions: estimated using input-output coefficients.
- Freight Productions: estimated using data from 1993 CFS.
- Trip Distribution: gravity model function in TRANPLAN was used to distribute the three trip types:
    - Internal-to-Internal (I-I)
    - Internal-to-External (I-E)
    - External-to-Internal (E-I)
- The Fratar Growth Factor model was applied for distributing the External-to-External (E-E) trip type.

Black, W. R. (1999). Commodity flow modeling. *Transportation Research Board*.

- TransCAD was used as GIS system.
- Data sources:
    - 1993 CFS
    - 1977 Census of Transportation
    - County Business Patterns
    - Carload Waybill Sample
- 18/19 commodity group identified
    - 19th commodity group is sum of five separate commodity groups
- Trip Generation: multiple regression analysis used for traffic production and attraction models.
    - Employment is key variable for traffic production.
    - Population is key variable for traffic attraction.
- Trip Distribution: fully constrained gravity model or entropy model.
- Modal Split: modal split computer model (NEWMODE) used to allocate trips to nine single modes or eight multiple mode categories.
- Traffic Assignment: all or nothing assignment to shortest path based on travel time.
- Sources of error:

    - Network does not account for local or county roads;
    - Some highways end at the state border;
    - External nodes placement errors;
    - Beyond circular highway network that surrounds Indiana, all highways are part of IHS.
    - Imports are missing;
    - Errors in generation and distribution models.

Chin, S. M., Hopson, J., & Hwang, H. L. (1998). Estimating state-level truck activities in America. *Journal of Transportation and Statistics*, *1*(1), 63-74.

- Data sources:
    - 1993 CFS
    - 1992 Census of Agriculture
    - 1992 Truck Inventory and Use Survey (TIUS)
    - 1993 to 1994 Transborder Surface Freight data
    - US Army Corps of Engineers 1993 US Waterway Data
    - Census Bureau's 1993 County Business Patterns
- Assigned CFS truck flows to routes predicted using the Oak Ridge National Highway Network.
- Problems:
    - Shipments from outside US are excluded from CFS.
    - US waterway Data lacks inland destination and mode of transportation.
    - Transborder data does not track shipment to final destination.

Jones, E. G., & Sharma, A. (2003, January). Development of statewide freight trip forecasting model for Nebraska. In *82nd Transportation Research Board Annual Meeting, Washington DC.*

- Examines transferability of a statewide freight forecasting technique developed for Wisconsin to Nebraska.
- Many states use trend line analysis of truck traffic counts to estimate and forecast statewide truck travel.
- Employment used to disaggregate the trips to the county level. Population data disaggregates the data to the TAZ level, zip-codes classified by their counties.
- Data sources:

  - 1993 CFS
  - Census of Agriculture
  - Census of Population
  - Economic Census
  - County Business Patterns
- Trip productions: estimated using 1993 CFS with supporting data from other censuses.
- Trip attractions: estimated using coefficients from the input-output analysis for Nebraska; uses IMPLAN Professional software package.

Waliszewski, J., Ahanotu, D., & Fischer, M. (2004). Comparison of commodity flow forecasting techniques in Montana. *Transportation Research Record: Journal of the Transportation Research Board,* (1870), 1-9.

- Uses Transearch and FAF data.
- Substate-level economic demographic data is applied to the tonnages in the base year.
- The state-level FAF data were allocated to counties by using county-level employment and population data.

Smadi, A., & Maze, T. (1996). Statewide truck transportation planning: Methodology and case study. *Transportation Research Record: Journal of the Transportation Research Board,* (1522), 55-63.

- Food and machinery production, the largest employment levels in manufacturing, selected for case study.
- Iowa Truck Weight Survey provided sample information on truck flow patterns; biannual survey covered 10,000 trucks in both 1989 and 1991.
- Travel time estimated using AUTOMAP.
- Used FORTRAN to find shortest paths.
- Freight productions based on zone employment; freight attractions based on input requirements and population levels.
- Distribution: gravity model using shortest time paths.
- Assignment: converted commodities into vehicle equivalents and assigned to least-travel-time routes; weights of vehicle equivalents estimated as average of all loaded trucks carrying commodity from Iowa Truck Weight Survey.

Harris, G. A., Anderson, M. D., Farrington, P. A., Schoening, N. C., Swain, J. J., & Sharma, N. S. (2012, August). Developing freight analysis zones at a state level: a cluster analysis approach. In *Journal of the Transportation Research Forum* (Vol. 49, No. 1).

- Disaggregation of FAF2 data in Alabama using cluster analysis; mentions that method would be difficult in Texas due to size.
- Data obtained on employment, payroll, shipment value, population, and personal income for all counties.
- State divided into zones based on interstate highway lines before cluster analysis.
- Freight distribution and assignment model used to calculate truck trip interchange and to forecast trucks.
- Applied gravity model for truck trip interchange.
- Assignment of trucks based on shortest paths, all or nothing.

2.2.3 National

Most national freight models are used for approximations, or are developed through methods that allow them to be applied regionally. Public data sources such as FAF and CFS are extremely popular, so the research team's recommendation to use alternative data sources will be an important research contribution. The models in the table were either national in scope, or contained generic aspects that can be applied to many different states.

Three of the four studies highlighted in Table 2.10 and Table 2.11 used FAF data, and none of the studies reported which commodities were studied. One study used the FAF regions as the unit of area of study, and the others used a county level of spatial resolution. Table 2.10 and Table 2.11 provide more information about each model.

Table 2.10: Commodity flow modeling, part 1

Study	**Incorporating Freight Value into the Urban Mobility Report** (Larson, 2010)	**GIS to Identify Strategic Freight Corridors in Texas** (Craig & Walton, 2002)
Description	"The goal of this research was to develop a method used to calculate the value of freight transported by tractor-trailer through U.S. states and urban areas."	"The goals of this report are to identify the strategic freight corridors (SFC) in the state of Texas."
Commodities Studied		
Data used	FAF, HPMS	Regional economic information system
Reason for data sources		The project required income data at the county level, broken-down by industry.
Data Limitations and Benefits	The paper had to estimate parameters to reconcile daily truck data with annual commodity data	
Spatial resolution	County level	County level
Use of data		The economic data was used to score counties. The top 10% received ten points, the next 10% received nine points, etc. The scores were combined with other variables to identify "economically significant counties"
Methods used	The model takes the total commodity value for an area (whole country in the paper) and apportions it to regions based on the HPMS data.	
Model Inputs and Outputs	The model provides regional commodity value amounts after receiving flow data by region and trucking flow patterns. The model distinguishes between value coming from a region, value going to a region, and value passing through a region.	
Tools used	No special tools required	GIS
Modes	Trucks only	Trucks only

Study	**Incorporating Freight Value into the Urban Mobility Report** (Larson, 2010)	**GIS to Identify Strategic Freight Corridors in Texas** (Craig & Walton, 2002)
Applicability for TX	Insofar as each corridor can be isolated to a region that the data has resolution for, this method could work. It probably would not help for regions with multiple corridors.	The paper identified forty-six economically significant counties in Texas, and identified strategic freight corridors that connect those counties. The corridors identified accounted for upwards of 90% of the value for the industries studied.
Model Strengths and Weaknesses	The model is simple and easy to calculate, but the resolution depends on the data, and the final model uses an adjustment factor based on known commodity values for some particular regions, and extrapolating the correction to the rest of the model.	The methodology deals more with identifying important areas (counties), and not with valuing specific corridors.

Table 2.11: Commodity flow modeling part 2

Study	**A Structural Direct Demand Model for Inter-regional Commodity Flow Forecasting** (Raneiefar, Chow, McNally, and Ritchie, 2013)	**Development of a Statewide Commodity Flow Distribution Model Using Composite Friction Factors** (Jin, Thomas G; Saito, Mitsuru; Schultz, Grant G., 2012)
Description	"A new framework for inter-regional commodity flow forecasting is presented to improve estimates of freight demand for inter-regional and statewide transportation models."	"This paper presents a new concept for distributing commodity flow transported by trucks among counties in a state, based on county-level total commodity flow available via the Internet"
Commodities Studied		
Data used	FAF3 for validation; Car Waybill Sample; "Elasticity of different factors on production, attraction and flow of different commodity groups with respect to industry-specific employment, population, industrial GDP, variables related to consumption and production of energy and land use variables, are studied"	FAF3
Reason for data sources	The methodology allowed for the integration of separate supply chains for different commodities; FAF is public	FAF3 was used due to its accessibility, and CFS data from FAF2 was used for calibration
Data Limitations and Benefits	The paper aggregated FAF's 43 commodity categories into 15 commodity groups	The model can distribute intrastate commodity flows without using any paid data source, but it had no reasonable data for validation at the time of publication
Spatial resolution	FAF Region	County level
Use of data	"The model integrates the generation and distribution steps by using simultaneous direct demand equations with structural relationships between dependent and independent variables"	The data (FAF3) was used to generate the parameters for a modified gravity distribution model, and the CFS data was used to calibrate the model
Method to estimate commodity flows and corridor values	The model creates an OD matrix—it does not assign the flows to corridors.	The model does not estimate commodity values on corridors. Rather, it focuses on the distribution phase of the four-step model to create an OD matrix of truck trips

Study	**A Structural Direct Demand Model for Inter-regional Commodity Flow Forecasting** (Raneiefar, Chow, McNally, and Ritchie, 2013)	**Development of a Statewide Commodity Flow Distribution Model Using Composite Friction Factors** (Jin, Thomas G; Saito, Mitsuru; Schultz, Grant G., 2012)
Model Inputs and Outputs	Explanatory variables were collected from public data sources. Employment and number of establishments, population, agriculture related variables such as farm acreages and tonnage of sold livestock, manufacturing sector GDP, energy-related data such as capacities of refineries, annual consumption and production of power plants of different types are examples of these variables.	The model requires county-level population data, as well as county-level employment by sector.
Tools used		
Modes	The model looks at trucking, rail, and truck-rail	Trucks only
Applicability for TX	A similar methodology could be used with better resolution data specific to Texas	This model could be used as is to estimate the distribution of commodity flows across Texas, but it would be less accurate at estimating truck trips. It is missing a mode choice step and does not estimate vehicle shipment sizes
Model Strengths and Weaknesses	The primary strength is that it integrates the freight generation and distribution steps	The primary purpose of this model was to develop a distribution methodology that can be applied to any state, and that does not require paid data sources

2.2.4 International

Though the commodity flow models done for international contexts may not use data sources relevant for Texas, the methodologies may still be options to use with relevant data. Tables 2.12 through 2.15 summarize the international commodity flow models described in Jong et al. (2012). More in-depth descriptions of the international models are provided following the tables.

Table 2.12: Summary of international freight transport models, part 1[1]

Model Name		Italian National Model System	SMILE/SMILE+	MODEV
Literature reviewed in addition to de Jong et al. (2012)		Marzano and Papola (2004)	Tavasszy et al. (1998)	Blardone (2007)
Year developed		2004	2005	2006
Study Area		Italy	Netherlands	France
Number of zones (internal + external)		267 internal zones	40 + 60 (NUTS2)*	342 + 230 + 25 ports
Number of commodities		8 consignment classes (4 weight classes each for perishable and non-perishable)	50 logistical families which are made based on value density, shipment size, etc.	10 NSTR1*
Choices included:	Generation	Yes	Yes	Yes
	Distribution	Yes	Yes	Yes
	Modal Split	Yes	Yes	Yes
	Assignment	Yes	Yes	Yes
	Logistics	No	Yes	No
Modes Included		Road, rail, and combined (road-rail)	Road, rail, IWW**, sea, air, pipeline	Road, rail, combined (road-rail), IWW**
Data Needed (if available)		Multi-regional input-output model (MRIO) tables, surveys of companies and shippers for utility model	Make/Use tables, production functions, demand functions, economic growth trends, much more	Socio-economic data for each zone for generation and distribution; cost and travel time of each mode
Advantages/Disadvantages		Allows for flexible interaction between transportation system and economic patterns; MRIO tables may not be available; assumes fixed production technologies	Very effective for analyzing the effects of different policies for many years into the future; analyzes effect of economic growth; the data requirements for good estimation are quite extensive	Has been used for long-term reference forecasts and for evaluating the impacts of potential infrastructure projects; accounts for empty truck trips; assignment is unimodal

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[1] Adapted from literature review by de Jong et al. (2012) as well as other sources if available

Table 2.13: Summary of international freight transport models, part 2[2]

Model Name		**BVWP**	**Transtools**	**Worldnet**
Literature reviewed in addition to de Jong et al. (2012)		N/A	Burgess et al. (2008)	Newton (2008)
Year developed		2007	2009	2008
Study Area		Germany	Europe	Europe (and trade with non-Europe)
Number of zones (internal + external)		439 (NUTS3)* + 112 (NUTS0-2)*	277 + 19 (NUTS2)*	≈ 1500 total (NUTS3)*
Number of commodities		10 NSTR1*	10 NSTR1*	10 NSTR1*
Choices included:	Generation	Yes	Yes	Yes
	Distribution	Yes	Yes	Yes
	Modal Split	Yes	Yes	Yes
	Assignment	Yes	Yes	Yes
	Logistics	No	Yes	No
Modes Included		Road, rail, IWW**	Road, rail, IWW**, sea	Road, rail, IWW**, sea, air
Data Needed (if available)		Socio-economic data for each zone for generation and distribution; stated preference data for mode choice	Most data is provided by ETIS database; e.g., PC matrices of base year, calibration and validation data	Data with regards to national economies for OD flow matrices; shipping costs
Advantages/Disadvantages		Has been used for forecasting in Germany for 2025; can be used for evaluating infrastructure projects; assignment is unimodal	Addresses mix of traffic (short/long distance and freight/passenger); identifies issues that require policy intervention; requires plethora of input info; Texas doesn't have database like ETIS	Models long distance travel; captures effects of globalization; model is publicly available; used to study ports in the past; model may be hard to implement on a single state as it is better to use for the entire US;

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[2] Adapted from literature review by de Jong et al. (2012) as well as other sources if available

Table 2.14: Summary of international freight transport models, part 3[3]

Model Name		**Norway**	**Sweden (SAMGODS)**	**ADA model for Flanders**
Literature reviewed in addition to de Jong et al. (2012)		de Jong and Ben-Akiva (2007)	de Jong and Ben-Akiva (2007); Vierth (2011)	de Jong et al. (2010)
Year developed		2009	2009	2010
Study Area		Norway	Sweden	Flanders (Northern Region of Belgium)
Number of zones (internal + external)		475 + 61	290 + 174	309 +22
Number of commodities		32 NSTR2*	35 NSTR2*	9
Choices included:	Generation	Yes	Yes	Yes
	Distribution	Yes	Yes	Yes
	Modal Split	Part of logistics	Part of logistics	Part of logistics
	Assignment	Yes	Yes	Yes
	Logistics	Yes	Yes	Yes
Modes Included		Road, rail, sea, air	Road, rail, sea, air	Road, rail, IWW**, sea, air
Data Needed (if available)		Very similar to Sweden except that CFS data is not available so an SCGE model is used	CFS data, sender and receiver data, transports costs, handlings costs, terminal data	Except for CFS data, the same as Sweden. Instead of CFS data, data from "Planet" model
Advantages/Disadvantages		Similar to Swedish model as the structure behind the models are the same	Logistic decisions are made at the firm level; gives "OK" results at the aggregated level; gives detailed results at the disaggregated level; adaptable to other regions of similar size (e.g., Flanders); difficult to validate	Similar to Swedish model as the structure behind the models are the same

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[3] Adapted from literature review by de Jong et al. (2012) as well as other sources if available

Table 2.15: Summary of international freight transport models, part 4[4]

Model Name		LOGIS	Netherlands (Basgoed)	NODUS model
Literature reviewed in addition to de Jong et al. (2012)		N/A	Tavasszy (2011)	Jourquin and Beuthe (1996); Pekin et al. (2008)
Year developed		2010	2011	2006
Study Area		Europe (focus on France)	Netherlands	Belgium or Europe
Number of zones (internal + external)		Not reported	40 + 30	≈ 600 in Belgium (NUTS5)*, ≈ 1500 in Europe (NUTS2)*
Number of commodities		10 NSTR1*	10 NSTR1*	10 NSTR1*
Choices included:	Generation	Yes	No	Yes
	Distribution	Yes	No	Yes
	Modal Split	Yes	Yes	Yes
	Assignment	Yes	Yes	Yes
	Logistics	No	No	No
Modes Included		Road, rail, combined (road-rail, IWW**	Road, rail, IWW**	Road, rail, IWW**
Data Needed (if available)		Socio-economic data for generation; data for mode choice models such as time, price, user preference, etc.	Inputs from SMILE+ for generation and attraction; network data; base year OD matrices for each mode	Require OD matrices as input, database of costs for the network of each mode type
Advantages/Disadvantages		Used for producing long-term reference forecasts and evaluating infrastructure projects and policies including environmental impacts; it does not have a logistic model and performs unimodal assignment	Replaced SMILE/SMILE+ due to its simplicity and ease of maintenance; able to answer most pressing policy questions; limited number of zones and commodity types	Easy to understand model for modal split and distribution; NODUS software has been given to UT Austin for academic purposes; requires OD matrices as input so it must be used alongside another model

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[4] Adapted from literature review by de Jong et al. (2012) as well as other sources if available

* NUTS – French acronym translated to Nomenclature of Territorial Units for Statistics. NUTS0 represents the national level. NUTS1 represents major social economic regions (larger regions/parts of a country). NUTS2 represents medium regions and megacities. NUTS3 represents small regions and some big cities. NUTS4 and NUTS5 have been replaced by Local Administrative Units 1 and 2 (LAU). LAU1 represents local government associations. LAU2 represents communities and municipality subdivisions. Figure 2.3 provides a map of NUTS3 regions for reference.

NSTR – Another French acronym for a nomenclature for 10 different commodity groups (0 to 9) to allow for transport statistics. The NSTR system has been replaced since 2007 by NST2007. Since it has been replaced, it was not discovered what commodity group is represented by each of the numbers.

** IWW – Inland waterway

Figure 2.3: NUT3 Regions in Europe, as Adapted from Wikipedia[5]

Italian National Model System

The Italian model jointly performs the generation and distribution steps through the use of multi-regional input-output models (MRIO models). MRIO models focus on simulating the amount of goods produced and traded among regions by analyzing the interdependence of different economic sectors. This is done through the use of MRIO tables that record how much goods from a sector in a specific region need to be produced in order to satisfy the demand for that good inside the region as well as for all exports from that region. The data needed for the implementation of this step comes from regional input-output tables (Marzano and Papola, 2004).

The Italian model has the advantage in that it uses elastic trade coefficients. Trade coefficients, which are part of MRIO models, allow for the estimation of the amount of trade inside each region and for the amount of trade from outside the region. The use of elastic trade coefficients allows for more accurate long term forecasts by accounting for changes in generalized transport costs. The Italian model finds trade coefficients through input-output tables or estimation surveys (Marzano and Papola, 2004).

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[5] NUTS4-5 are no longer in use but any number lower than NUTS3 represents larger zones and any number greater than 3 represents smaller zones

The modal choice step is performed via a random utility model for each consignment class. In order to create the random utility model, a database of interviews of Italian firms and shippers is used. The model uses eight different consignment classes by having four weight classes for perishable goods and four for non-perishable goods (< 3.5 T, 3.5-16 T, 16-30 T, >30 T). These consignments can be further segmented by whether they are containerized or not (for perishable consignments) and their value/weight ratio and consignment frequency (for non-perishable consignments). The probability of selecting a specific mode is calculated through the utility of each mode inside a multinomial logit model (Marzano and Papola, 2004). Assignment is done jointly with modal choice as the route taken (and the accompanying cost/travel time) will affect the utility of each mode. Marzano and Papola (2004) note that all four steps (generation, distribution, modal split, and assignment) are interrelated because the very same variables that may affect modal split and assignment may also have impacted the MRIO tables used for the first two steps.

SMILE/SMILE+

Before 2005, the Dutch SMILE and SMILE+ models (Strategic Model for Integrated Logistic Evaluations) were the only national freight models with endogenous logistics. The SMILE model had been completed by 1997 and SMILE+ represents improvements to the model that were completed by 2005. The main difference between SMILE and SMILE+ is the fact that SMILE+ uses an MRIO model for production and attraction (de Jong et al., 2012). The literature for SMILE+ was not available as it was only presented a conference. Thus, the following review applies to SMILE, while we can expect that SMILE+ is similar.

SMILE is especially useful because it allows the user to answer questions about the effects of many different policies. For example, one might test how freight flows on a road might change if a new road is constructed. This allows the user to run many different scenarios and decide which of the scenarios yield the highest benefits. The plethora of variables that can be varied in each scenario include cost factors (storage, transport, handling), traffic and network characteristics, supply aggregates (production value, consumption, export) and more. Another example of a question that SMILE can answer is how economic growth will change infrastructure and transport needs (Tavasszy et al., 1998).

The main strength of SMILE lies not in estimating current freight flows but in forecasting freight flows in the future under a plethora of policy scenarios. Further, not only are freight flows forecasted but also many other variables that might be relevant to the entire Dutch economy and transportation network. The developers of SMILE also pride themselves on the fact that their forecasts are not outputs for only one horizon year but they are able to forecast what happens before and after that year as well (Tavasszy et al., 1998).

SMILE uses a database to acquire many of the necessary inputs. The database contains information on the following (Tavasszy et al., 1998):

- 542 types of products, which are sorted into 50 logistical families based on variables such as value density, demand frequency, and shipment size
- road, rail, inland waterway, air, pipeline, and sea networks
- variables concerning relationships of different agents
- sectoral and spatial exchanges (production functions and OD tables)

- parameters of logistics choice functions

In order to estimate OD tables, Make/Use tables are used. Make/Use tables provide insight into the production factors connected to the activity of each sector, including the commodities that are produced and consumed. This allows for the construction of product chains that when combined further results in production networks. This in turn allows us to answer questions such as "how will freight flows change if there is a 20% replacement of steel by composites in the car manufacturing industry?" However, developing Make/Use tables requires the development of production functions (Tavasszy et al., 1998). Figure 2.4 shows the outline of steps in SMILE/SMILE+ and the inputs required. Obviously, depending on the type of analysis, some steps may not be required, such as the emissions step if it is not of interest.

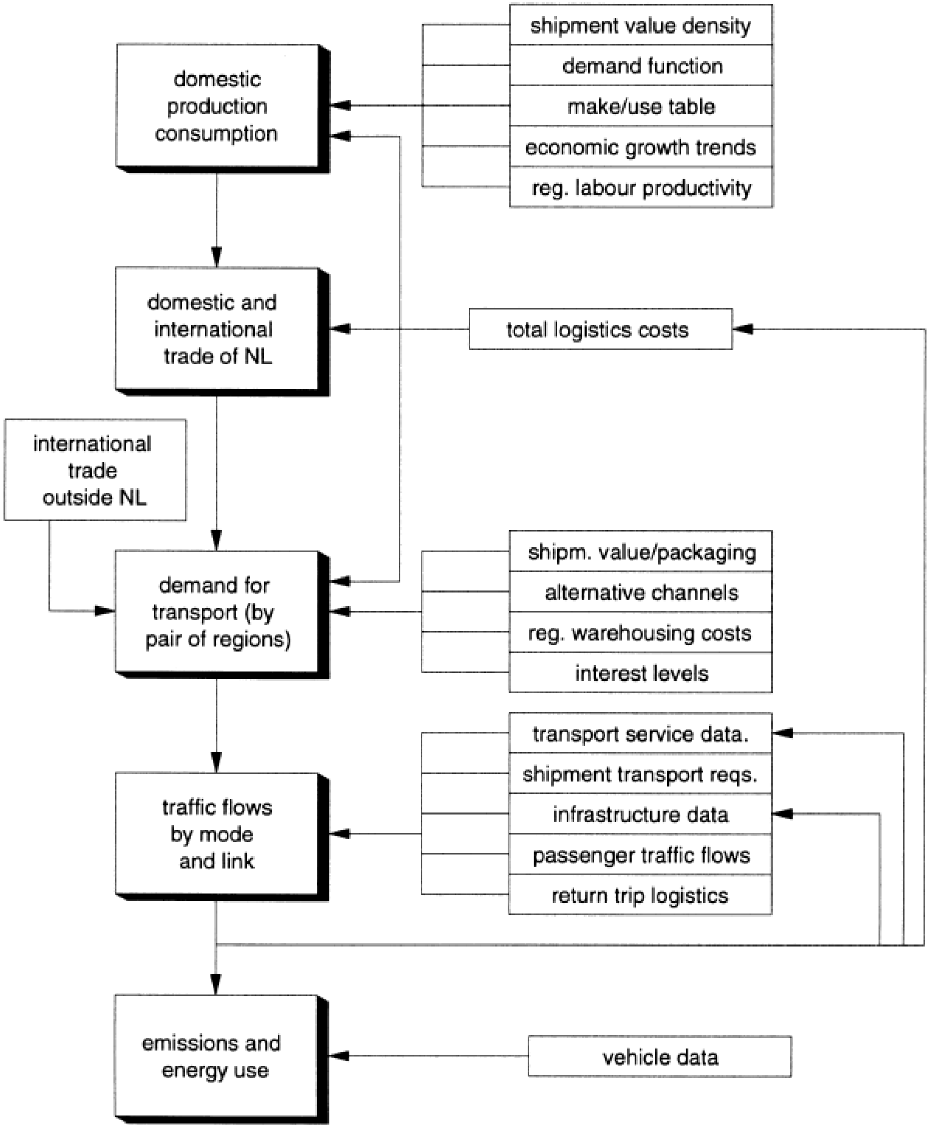


Figure 2.4: Outline of Steps within SMILE (Tavasszy et al., 1998)

MODEV and BVWP

MODEV is a French model that has five main steps. In addition to the four main steps in freight transport models (generation, distribution, mode choice, assignment), this model adds a step between mode choice and assignment to calculate the number of selected vehicles needed to ship all the goods that are being moved (Blardone, 2007). Other models do this as well, although it is usually not a separate step.

The generation step is performed based on regression models that use socio-economic variables for each zone. Thus, in order to perform generation, socio-economic data is required as well as sample supply/demand data for each zone with which the model can be developed. The distribution step is a gravity model based on the distance between the zone of origin and zone of destination. The mode choice step uses a utility logit model based on the travel time and cost of transport. The mode choices are truck, rail, truck, and rail combined, and inland waterway. Once the mode has been selected, the number of required vehicles of that mode is calculated by dividing the total amount to be shipped by the average product load. Assignment in this model is unimodal, which means that we cannot account for transport chains (Blardone, 2007).

MODEV is very similar to the German BVWP model. Generation and distribution are done the same way for both of the models. For mode choice, on the other hand, a utility model is developed based off of not only travel time and cost of transport but also on disaggregate data acquired from stated preference studies. The mode choices are the same as for MODEV except for the fact that a truck-rail combination is not an option. Additional sub-models allow for sea freight and air freight to be selected. Assignment is unimodal just as with MODEV (de Jong et al., 2012).

Transtools

The Transtools model was developed for the European Union to use in analysis of freight demand and passenger demand in unison. There are separate freight and passenger demand models, but the network assignment model takes the output of both models at the same time (Burgess et al., 2008). This is shown in Figure 2.5. Transtools, Worldnet, and LOGIS are the only models reviewed that are specifically developed to be used for large areas, like Europe (de Jong et al., 2012).

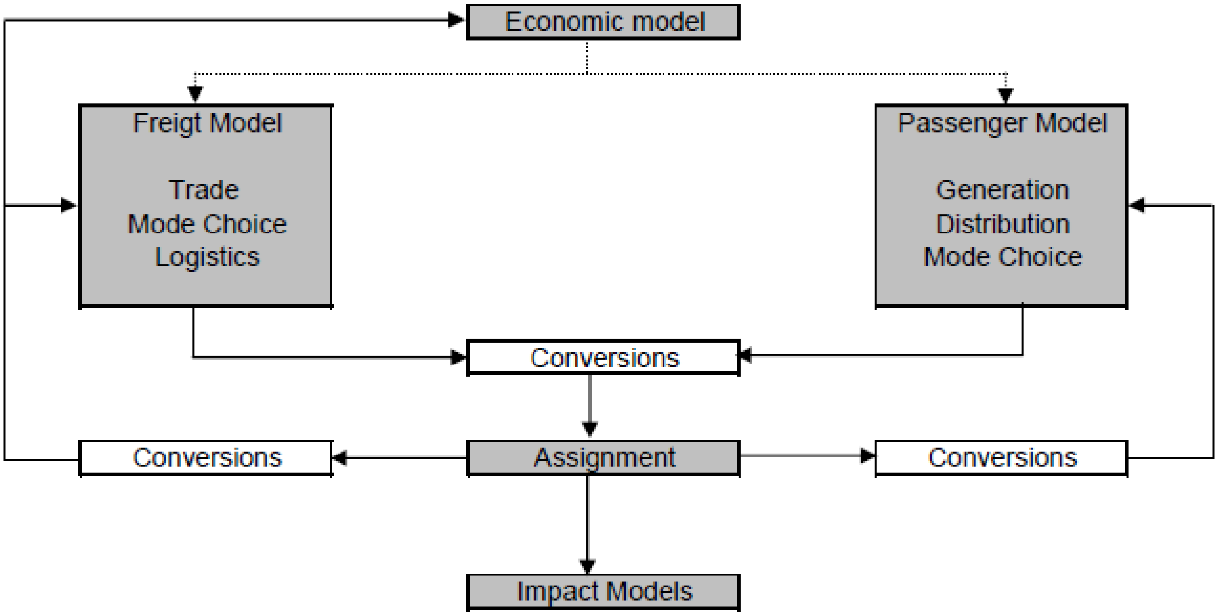


Figure 2.5: Structure of the Transtools Model that Combines Freight and Passenger Models (Burgess et al., 2008)

For the freight model, Transtools acquires an OD freight transport matrix for its base year from the ETIS database (European Transport policy Information System). ETIS was developed for the purpose of providing a reliable database for all European transport models in order to assist with problems such as fragmentation of data sources, missing data, lack of harmonization, and difficulty of access and use of data (Chen, 2011).

For Transtools, ETIS quantifies the generation and attraction of flows of goods between each of the trading regions for the base year. At the time of Burgess et al.'s publication (2008), the base year was 2000. ETIS also provides information on trade matrices (e.g., origins and destinations of commodities, commodity type, cargo type, etc.), transport matrices (origins and destinations of vehicles, commodity being carried by each vehicle, etc.), and transshipment matrices (transshipment locations and capacities, incoming modes, outgoing modes, origins and destinations of vehicles/commodities, etc.). In turn, the freight model of Transtools outputs a forecast OD matrix for each commodity that is not only for the original origin and the final destination but also for all intermediate transshipment points. The output will include the mode used between all legs of the supply chain as well as the weight transferred during each leg (Burgess et al., 2008).

In order to do the mode split step, a utility multinomial logit model is performed. The four mode choices are road, rail, inland waterway, and sea. After the mode choice model, a module called SLAM (which is a part of the SCENES model) is used for logistics (Burgess et al., 2008). SLAM takes the PC matrices (Production-Consumption matrices—these are equivalent to the original origin and final destination) and converts them to multiple OD matrices along the shipping chain (e.g., from origin to transshipment point to another transshipment point to final destination) in three stages (Combes and Leurent, 2007):

- A small set of regions with distribution centers is generated based on economic activity, centrality with respect to place of production and place of consumption, and accessibility to the various infrastructure networks.
- A number of candidate logistic chains are generated whereby each commodity can travel between zero to two distribution centers. The generalized cost of each chain is then evaluated based on transport costs, inventory costs, and logistics cost.
- Lastly, the commodity is assigned to a candidate chain according to a nested logit model where the chain type is determined at the upper level and the geographic location is determined at the lower level. Thus, the output will yield OD matrices between zone of production, consumption, or a logistic chain.

Following this step, assignment is done for passengers and freight. Assignment is unimodal based off the results from the freight or passengers models (Burgess et al., 2008). However, since there is a logistics module inside the freight model as shown in Figure 2.5, unimodal assignment is acceptable.

Worldnet

Worldnet is a freight model that captures long distance shipments. The big advantage over most other models is the fact that most other models will not capture the entire supply chain (including transshipment points) if the commodity being shipped is being exported into/imported from an external zone. Thus, Worldnet is a long distance, multimodal OD matrix, and a network model that will cover Europe, its neighbors, and even some intercontinental routes. This allows the user to analyze the impacts of globalization on transport networks. The large scale ability of this model may be applicable to the US but a single state may be too small for the use of the model (Newton, 2008).

For traffic generation at the national level, a world trade model, such as a gravity model, is used. To subdivide the trade flows, a regional distribution model is applied at the NUTS3 level. Lastly, a multimodal assignment procedure is used to assign transport chains (Newton, 2008). Thus, even though Worldnet does not have a separate logistics sub-model, it is still able to build transport chains (de Jong et al., 2012).

Worldnet is a successor to ETIS/Transtools and therefore many of the goals and the data required are the same as for Transtools (Newton, 2008). A major difference between Transtools and Worldnet is the fact that Worldnet focuses on trade with non-Europe and the fact that Worldnet uses about 1500 NUT3 regions whereas Transtools uses about 300 NUTS2 regions (de Jong et al., 2012).

Norway, Sweden, and the ADA Model for Flanders

Due to the large similarities between the Norwegian and Swedish models, they are reviewed in unison. The two models are not the same but they use a common structure; their main differences arise from the types of data available in Norway vs. Sweden (de Jong and Ben-Akiva, 2007).

If available, CFS data is used to develop PC (or PWC, Production-Wholesale-Consumption) matrices. If CFS data is not available (as is the case for Norway) a spatial computable general equilibrium model (SCGE) can be used (de Jong et al., 2012). This data is then disaggregated in order to find firm-to-firm matrices (de Jong and Ben-Akiva, 2007). Then, logistic decisions are made to approximate the transport chain composition. This means that each leg in the transport chain needs to have an origin and destination as well as a mode type. The origin and destination of each transport leg can be the place of production and consumption but they can also be intermediate locations that may serve as inventory or transshipment nodes. This means that the shipment of one commodity may include multiple origins and destinations as the commodity makes its way from the producer to the consumer. After this logistic step, flows from each origin to each destination (including the intermediate origins and destinations) are aggregated for each commodity to output the amount of required vehicles types for each mode. Then, the road network assignment step can be performed (de Jong and Ben-Akiva, 2007). This procedure is shown in Figure 2.6.

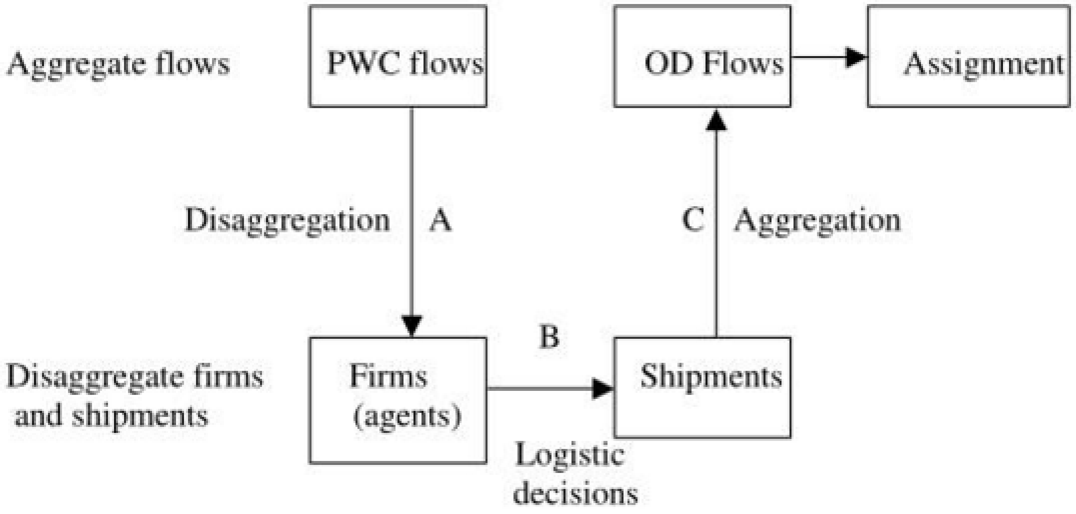


Figure 2.6: Steps Used for Swedish and Norwegian National Models (Karlsson et al., 2012)

The model approximates shipment size by minimizing the function for total logistics costs. However, many constants in the equation to decide on optimal shipment size must be approximated or assumed such as, for example, the fraction of shipment of a certain commodity that is lost or damaged (de Jong and Ben-Akiva, 2007).

The model accounts for a shipment switching modes, being stored in inventory, and being consolidated into larger shipments (via consolidation centers) or distributed into smaller shipments (via distribution centers). Thus, for each leg of a transport chain, the model assigns a mode type and a specific (intermediate) destination for that leg. A specific transport chain is selected using a utility choice model based off of the costs of the transport chain. The utility model also includes a random error term for the effects of variables that may have been missed in the cost calculations (de Jong and Ben-Akiva, 2007).

There are a few different types of data that the model requires in order to estimate the logistics module. First, data on individual shipments is required. This includes things such as the sector of each sender and receiver, the origin and destination, the value of goods, the mode choice and the size of the vehicle used, and the shipment size (or frequency). Also needed is information that pertains to freight terminals and consolidation and distribution centers such as their locations and capacities. Lastly, transport and logistic costs are needed: these include transport costs per vehicle per unit of distance, terminal costs, and handling and storage costs for all alternatives. For many countries, much of the disaggregate data needed is not available but it is still possible to calibrate the model to aggregated data so that, for example, instead of knowing the exact sender and receiver of a shipment, it is enough to know the OD zones (de Jong and Ben-Akiva, 2007).

The ADA (aggregate-disaggregate-aggregate) model for Flanders, which is one of three Belgian states and is located in the north side of the country, is implemented by calibrating the Norwegian/Swedish model to Flanders. Rather than needing a CFS, PC matrices were already available from an existing trade model called Planet (de Jong et al., 2010). The ability to implement the Norwegian/Swedish model in a country of similar size suggests that the model has great potential. However, no case study was found that implemented this model on a larger country comparable to the size of Texas (Texas is a little more than twice the size of Norway).

NODUS

NODUS is a GIS-based software for modeling the flow of goods in Europe. NODUS has been applied at NUTS5 for Belgium and at NUTS2 for other European countries (Pekin et al., 2008). Thus, it has the ability to be applied on multiple spatial levels. However, NODUS's greatest advantage comes from its framework's ability to account for mode choice, network assignment, and potential "multimodal chains" all at the same time.

This is done by creating what are called "virtual networks." A virtual network allows us to account for possible loading and/or unloading at a node, as well as transshipment (mode change), and transit (proceeding through the node without stopping). An example of three links going into one node is shown in Figure 2.7 in a regular network and a virtual network (Pekin et al., 2008). Looking at the real network on the left side of the figure, there are three links going into node a. One link is W2 which means that is an inland waterway, represented by the W, and that it can accommodate two different types of water modes (e.g., small ship and big ship), as represented by the 2. Similarly, W1 is an inland waterway that can only accommodate one type of water mode such as a small ship (e.g., due to the waterway's smaller size, for example). The last link, R1, represents a rail link (R) that only allows for one type of train (1).

Next, in order to account for all of the activities that can occur at the node (loading/unloading for storage at a node, transshipment, and transit) we convert the real network into a virtual network as shown on the right side of Figure 2.7. This network records the costs for each of these activities by storing their costs on the "virtual links" on the interior of the diagram (Pekin et al., 2008).

Looking at a1W1: "a" denotes that we are looking at node a; the first "1" denotes that we are looking at the first link in the real network; W denotes that this is an inland waterway; the second "1" denotes that we are looking at the "first" ship type (e.g., the small ship). Likewise, for a1W2, everything is the same except for the fact that we now looking at the "second" ship type (e.g., the big ship). With the second link, a2W1, we only have one ship type (the small one). Similarly, third link, a3R1, only has one train type. Lastly, a000, does not represent a link but simply represents the storing of freight at node a.

Since the costs of any activity are placed on these virtual links, it is now possible to perform traffic assignment and determine what path should be used to find the minimum cost of travel. In this case, the path would not only contain the physical path (as with regular traffic assignment) but would also contain what mode is being used, if modes are ever changed, and if freight is ever stored at a node. For example, going from link a1W1 to a3R1 would mean that the freight on a small boat is unloaded and placed on a train with a specific cost. Similarly, going from a1W1 to a2W1 would mean that a small boat simply passes through the node without any activity. Thus, this (lack of) activity would not incur any cost. This is why it is a dashed line in the diagram.

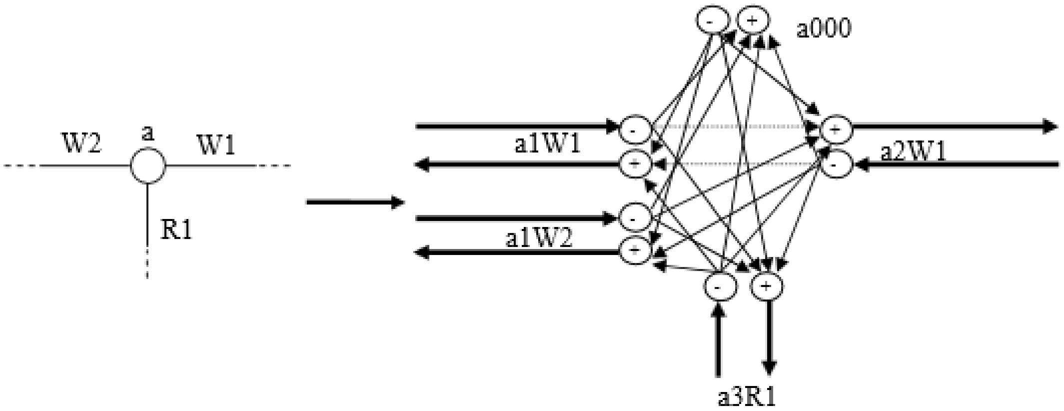


Figure 2.7: NODUS Change from a Real to a Virtual Network (Pekin et al., 2008)

NODUS has its own existing database that is geared for modeling in Europe. If NODUS were to be mimicked for the US or for Texas, then it would be necessary to create another database. The database would have to contain railway, inland waterway, and road networks (Pekin et al., 2008).

In addition, as inputs, NODUS requires a freight demand OD matrix. This means that NODUS only performs Steps 3 and 4 of the four-step freight demand model. Cost functions for each of the activities at each node are also required as inputs (cost of loading/unloading, transshipment, and transit). As an output, NODUS will provide the mode types that will carry the freight in consideration and the path taken (Pekin et al., 2008). The biggest assumption of this model is that it assumes that the optimal solution found by NODUS is what is actually being used in the real-world (Jourquin and Beuthe, 1996). However, often, businesses may not use the cheapest available solution for a number of reasons.

LOGIS

LOGIS is a freight transport model for Europe with a focus on flows originating and ending in France. Generation is done via regression models using socioeconomic data. Distribution uses gravity models. Logit models are used for mode split and for unimodal assignment. There is no sub-model used for logistics. In the past, it has been used for evaluating infrastructure projects and policies (de Jong et al., 2012).

Netherlands (Basgoed)

The Dutch model, Basgoed, was developed as a replacement model for the older SMILE/SMILE+ models as the Dutch MoT wanted a simpler and more straightforward freight model that would be easier to maintain. Partially due to its simplicity, it is able to analyze less zones/commodities than its predecessors. Nonetheless, it is still able to answer the most pressing policy questions (de Jong et al., 2012).

Basgoed uses a conventional four-step model; as of 2012 it still did not include a logistics sub-model, as shown in Figure 2.8. Inputs from SMILE+ are used for generation (de Jong et al., 2012). Distribution is done using a gravity model and mode split is done with an aggregate multinomial logit utility function with the explanatories variables being cost and region. The assignment sub-model is unimodal (de Jong et al., 2012).

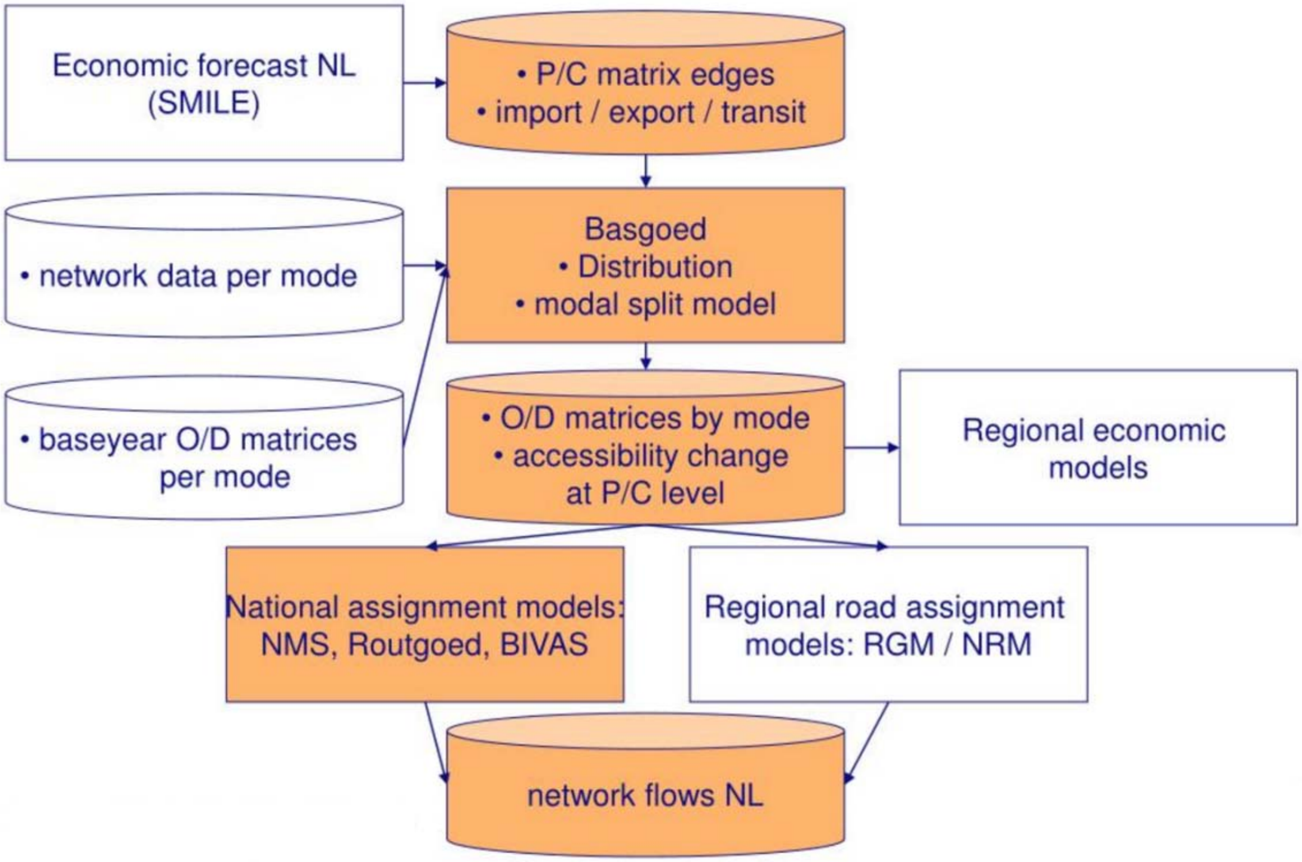


Figure 2.8: Basgoed Flowchart (Tavasszy, 2011)

2.3 Models for Specific Commodities

In the 2011 report Freight Planning for Texas—Expanding the Dialogue (Center for Transportation Research, 2011), the following relevant observations were made:

- The first main approach to estimating freight demand, represented by the FAF model constructed by the FHWA, uses survey data and iterations of matrix statistics (similar to the traditional four-step model) to forecast freight flows and network flows.
- A second approach is exemplified by the Ohio River Navigation Investment Model (ORNIM) and the Navigation Economic Technologies (NETS) program. These models estimate freight demand based on optimization techniques that balance the benefits and costs of a freight operating system.
- Most DOTs rely on the CFS data, or more recently the FAF data, the Transearch database, or interviews/surveys of freight stakeholders.

- The FAF data are very valuable for aggregate types of analysis and corridor-level analysis. However, more detailed data—freight flows assigned to more of Texas's transportation system—are required for statewide freight planning.

As popular as FAF and economic/socioeconomic variables are for use in commodity flow modeling, applying the same modeling approach across all commodities becomes problematic for commodities with unique attributes not compatible with the approach. This was noticed by Ahanotu et al. (2003), and even the draft Texas Freight Mobility Plan pointed out that in the cattle industry in Texas, less than one-third of cattle operators claim farming as their primary occupation. A commodity flow model that relies on reported employment for all industries for estimating commodity generation would not provide an accurate result for an industry such as the cattle industry.

Taking a commodity-specific approach allows the modeler to select the datasets that best capture data about the industry and commodity supply chain. This tailored approach opens up opportunities to pursue a variety of methodologies that best fit the types of data available for the commodity. The next section summarizes three papers found in the literature that took a commodity-specific approach.

The first paper highlights the benefits of using sources specific to a commodity to overcome the weaknesses of commonly used datasets for modeling. Shabani, et al. (2014) initially used Transearch, FAF3, and US Census VIUS data to estimate commodity flow of coal and gas, but found Transearch data had incorrect distribution, mode shares, and tonnage for both coal and crude oil commodities. They instead used data sources from the Utah Geological Survey; Utah Division of Oil, Gas & Mining; and US Energy Information Administration, and achieved better results.

The second paper, by da Silva & D'Agosto (2012), highlights the benefit of using commodity-specific data sources for achieving higher spatial resolution. These researchers created a model to estimate the OD matrix for soybean production in Brazil using:

- Soybean production data (tons/year) available at the municipal level (aggregated to the meso-region) at the origin from the Brazilian Institute of Geography and Statistics, and
- Export data (tons/year) from the System of Analysis of Foreign Trade Information (Bureau of Foreign Trade) from ports where soybeans are exported as the destinations (using a constrained gravity model to distribute the soybeans produced to the ports).

Lastly, the third paper highlights how commodity-specific data allows for modeling of the facilities of the supply chain of the commodity. Kolesnikov et al. (2012) state "In this work, we focus on a much narrower problem of estimating the freight flow of a particular commodity, and we have the advantage of knowing the locations of the agents in a distribution network." Using data from the Environmental Protection Agency's storage container data for chlorine that includes the location and amount of chlorine at each facility, the authors were able to classify each facility as producers, wholesalers, or consumers of chlorine using the NAICS (North American Industry Classification System) codes for the facility (Figure 2.9). With the location, supply, and demand of the facilities known, the model proceeds to use optimization techniques to estimate the road transport of chlorine in the US.

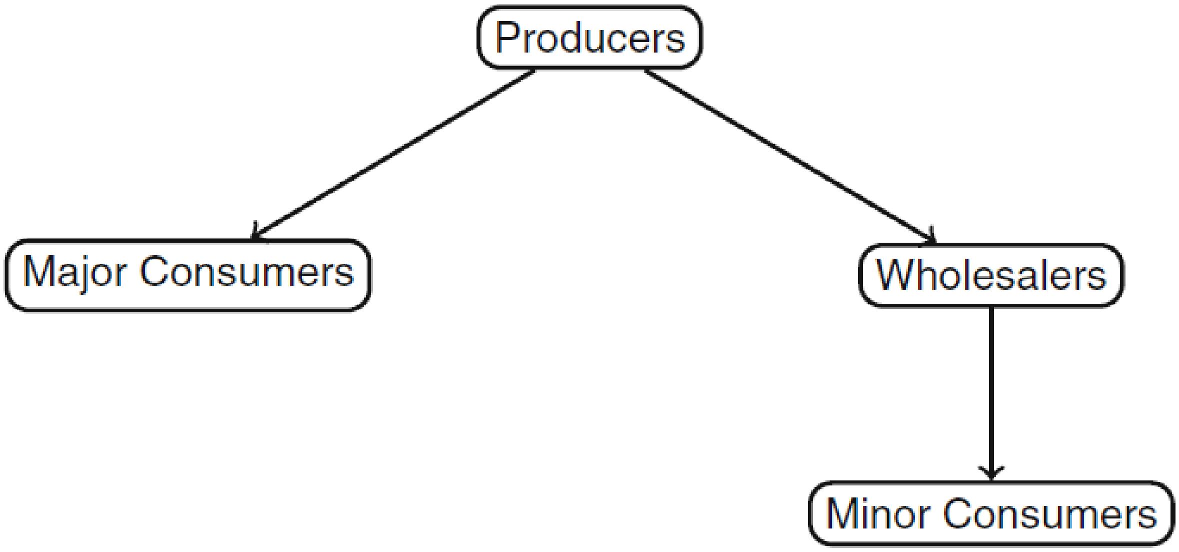


Figure 2.9: Abstract Model of the Chlorine Network (Kolesnikov et al., 2012)

Those three papers, as well as the findings from papers such as Ahanotu et al. (2003), motivated the CTR research team to explore a commodity-specific approach for this project.

2.4 Summary

The research team conducted a literature review focused on finding commodity flow estimation methods for the local/substate, state/region, and national levels in the US and in other countries. The initial findings indicate similarities in data sources (e.g., Transearch, FAF, and CFS) and methodology (applied general approach to all commodities; usually variations of the four-step transportation model) for determining flow and assignment to network. A few articles, though, did not use those traditional data sources and methodologies, and instead used data specific to the commodities (examples included chlorine gas, soybeans, and coal and gas). In the case of coal and gas, the paper indicated the Transearch data did not provide the best results for the commodities evaluated compared to use of data sources specific to those commodities.

Those findings, and the unique opportunity to develop a methodology tied more closely to the uniqueness of a commodity, motivated the research team to pursue commodity-specific data sources and modeling methodologies. The following chapter summarizes the selection of the commodities for modeling.

Chapter 3. Commodities Selection

The research team selected commodities to consider for commodity-flow modeling based on a review of FAF4 search results for top-ranked commodities by value and weight, top-ranked agricultural commodities by cash receipts, and the commodities section of the Office of the Governor's key industry sectors.

3.1 Top FAF4 Commodities

Using the FAF4 query tool, the research team compiled different top 10 lists of commodities for each type of movement (exports, imports, through, and within the state) using different selection criteria (e.g., by mode and destination) and selected the commodities appearing frequently in those lists or top ranking in one or more:

- Gasoline
- Fuel Oils/Biodiesel
- Basic Chemicals
- Plastics/Rubber
- Textiles/Leather
- Base Metals
- Metal, articles of
- Machinery
- Electronics
- Motorized Vehicles

3.2 Top Agricultural Commodities

Agriculture did not appear in the FAF4 results. However, the research team felt it was prudent to include agricultural commodities in the commodity-flow modeling. The Texas Department of Agriculture listed these as top agricultural commodities in Texas in 2012:

- Cattle ($10.5 billion)
- Cotton ($2.2 billion)
- Milk ($1.8 billion)
- Broilers ($1.7 billion)
- Greenhouse/Nursery ($1.3 billion)
- Corn ($1.2 billion)
- Grain Sorghum ($594 million)
- Wheat ($538 million)

- Vegetables ($439 million)
- Eggs ($439 million)

3.3 Texas Governor's Office Key Industry Sectors

The draft October 5, 2015 Texas Freight Mobility Plan specifically mentions that the Texas Governor's Office has an economic development vision to build a competitive advantage in these six target industry sectors:

- Advanced technology and manufacturing
- Aerospace, aviation, and defense
- Biotechnology and life sciences
- Information and computer technology
- Petroleum refining and chemical products
- Energy

Because of the importance of those industry sectors to the state's economic development, the research team identified the potential commodities in those industry sectors to consider for commodity flow modeling. The industry sectors are rather wide, and some of them do not really involve trucking of commodities across the state (either moved by another mode, such as pipeline or rail, or they are more of a service industry). In addition, some of the industry sectors produce the commodities already listed in the Top FAF4 commodity listing. However, the research team did identify some commodities for testing, as presented in the following section.

3.4 Recommended List of Commodities to Test

After reviewing and researching modeling opportunities for the FAF4, agricultural, and key industry sectors, the research team recommended the following list of commodities for modeling:

- Top five agricultural commodities (cattle, cotton, milk, chickens, greenhouse)
    - List includes corn, grain sorghum, and leather as part of the cattle supply chain
    - Inclusion of cotton and leather captures top FAF textiles/leather commodity
- Gasoline
- Ethanol (for fuel oils/biodiesel)
    - Including corn as part of the ethanol supply chain
- Plastics/rubber
- Sulfuric acid (for basic chemicals)
- Steel (for base metals and metal articles)
- Aerospace manufacturing

- Motorized vehicles (automobiles and pick-up trucks)
- Electronics (consumer electronics US-Mexico)

The October 5, 2015 draft Texas Freight Mobility Plan provides under a subheading of “Critical Texas Supply Chains” five examples of supply chains in Texas for the automotive, beef, cotton, electronics, and gasoline industries because of their importance in some way to the Texas economy and freight transportation. All of those were included in the recommended list of commodities to test.

3.5 Commodities Not to Test

Though petroleum and coal stand out as high volume commodities in Texas and important to the Texas economy, they are not recommended for commodity flow modeling. In contrast to gasoline, most petroleum is moved by pipeline to petroleum refineries (see Figure 3.1), and therefore is not recommended for modeling due to limited impact on TxDOT roadways. Similarly, coal is moved mostly by rail (not road) to coal power plants (see Figure 3.2).

Figure 3.1: Petroleum Pipelines and Refineries in Texas

Figure 3.2: Coal Power Plants and Mines

Among this initial list of recommended commodities, aerospace manufacturing, milk, leather, and cotton are not studied further. Aerospace manufacturing was not studied because of the extensive lists of companies and lack of data providing enough information on the connections between the companies. For milk, CTR had already performed a legislative analysis of the milk production, processing, and transport for Texas for a proposed house bill (HB 3129) in 2015. The HB analysis summarized the milk facilities and production in a table. That data provides the locations and supply. An Excel spreadsheet was prepared for the legislative analysis reports the pounds and gallons of milk, number of cows, and number of milk processors in each county in Texas. Leather and cotton were also skipped due to the lack of available data.

Chapter 4. Commodity Flow Estimation Procedures

The commodity flow estimation procedure involves finding commodity-specific data sources, creating county-to-county OD flows, performing network analysis, comparing results with existing databases, and incorporating impact of seasonal variation and congestion. The general procedures of these steps are described in this chapter. The detailed analysis results are presented for each commodity in Chapter 5.

4.1 Finding Commodity-Specific Data Sources

For each selected commodity, the research team worked on finding data sources that can be used to estimate the trip generation, trip attraction, trip distribution, and transportation mode through online search and communication with industry representatives.

The traditional data sources listed below are discussed in more depth in NCFRP Report 35 *Implementing the Freight Transportation Data Architecture: Data Element Dictionary* and the associated freight data dictionary. The CTR research team recommended that these data sources be used for comparisons with the commodity-specific approach of this project and in other tasks as needed, but that they not be the primary sources of data used for the commodity-specific approaches, since the goal was to use data specific to commodities to develop commodity flow models reliant on data unique to a commodity, and thus potentially better for modeling the flow of the commodities through the supply chain.

- 2007 and 2012 CFSs
- American Transportation Research Institute (ATRI) Truck GPS data
- Bridge Inspection and Appraisal Program (BRINSAP)
- County Business Patterns (county and zip-code level)
- FAF version 3
- IHS Global Transearch database
- North American Transborder database
- Pavement Management Information System (PMIS)
- Safety and Fitness Electronic Records (SAFER) System
- US Census Bureau Foreign Trade Statistics
- Vehicle Classification from Texas Data Management System (TDMS)
- Vehicle Inventory and Use Survey (VIUS)

For some commodities, the team found rich datasets unique to the commodity that allowed for the creation of extensive county-to-county OD flows (or alternatively, an understanding that most flow stays within one county), whereas for some other commodities, datasets were difficult to find or incomplete, or the supply chain became too nebulous (i.e., too many uncertainties and assumptions associated with connecting facilities in the supply chain). In Chapter 5, the datasets used for estimating commodity flow will be discussed in detail for each commodity.

4.2 Creating OD Flows

Using the commodity-specific data sources, the research team estimated a county-to-county flow matrix for each commodity for selected sections of the supply chain. The modeling methodology is commodity-specific and depends on the data available. Generally, production data were either collected at the state level and then distributed to trip generation facilities based on their production capacity or directly obtained from available county-level data (e.g., the US Department of Agriculture [USDA] provides county-level production data for many agricultural products). Consumption was usually estimated based on the receiving facility's capacity, receiving county's population, or other data representing the destination county's or destination facility's demand for the commodity.

After production and attraction at the county or facility level were estimated, if information about how the commodities move from their origins to their destinations was available, trips were distributed based on this information (e.g., according to industry representatives, some cattle feedyards and slaughterhouses are vertically integrated, while corn and grain sorghum are usually sent from farm to the nearest elevator, etc.). Otherwise, trips were distributed based on certain types of gravity models. When the impact of congestion was not considered, distance was usually used as the impedance of the gravity model. Travel time between the origin and destination was used as the impedance of the gravity model when the impact of congestion was taken into consideration.

After distributing commodity flows between origin and destination pairs, a county-to-county flow matrix was obtained for each commodity. The research team then collected information regarding the typical type of trucks used to transport each commodity. The weight/capacity limit of the truck and the unit weight/volume of the commodity was used to calculate the amount carried by that truck type. With this information, the commodity flow matrix could be converted to the truck matrix, with each cell of this matrix indicating how many trucks are used to move the commodity between the OD pair annually.

The truck matrices can also be converted to value matrices based on the value of commodities carried by each truck, which can be calculated by multiplying the number of commodities carried by each truck and the unit price of the commodity. The unit price of each commodity was estimated based on prevailing market trends in force when the commodity data was gathered. Chapter 5 describes the detailed process of estimating commodity OD flow, identifying typical truck types, and converting flow matrix into truck matrix and value matrix for each commodity.

Truck trip and value matrices of each commodity are included in the Appendix 1 of this report.

4.3 Performing Network Analysis

Network analyses were performed for each commodity after developing a county-to-county truck matrix and value matrix so that link-level estimation of truck volume and commodity values could be obtained. The general procedure of network analysis is described in this section. Detailed analysis results for each commodity are presented in Chapter 5.

4.3.1 Network Creation

In order to assign truck trips and the value of commodities to the Texas primary and secondary freight networks, a network was created in TransCAD using the Texas SAM and GIS data obtained from TxDOT. Using a feature in TransCAD, the GIS layer was overlaid to select the appropriate links on the Texas SAM network. The network was then manually scanned to ensure that all required and necessary links were selected. Figure 4.1 illustrates the scope of the network within the state of Texas.

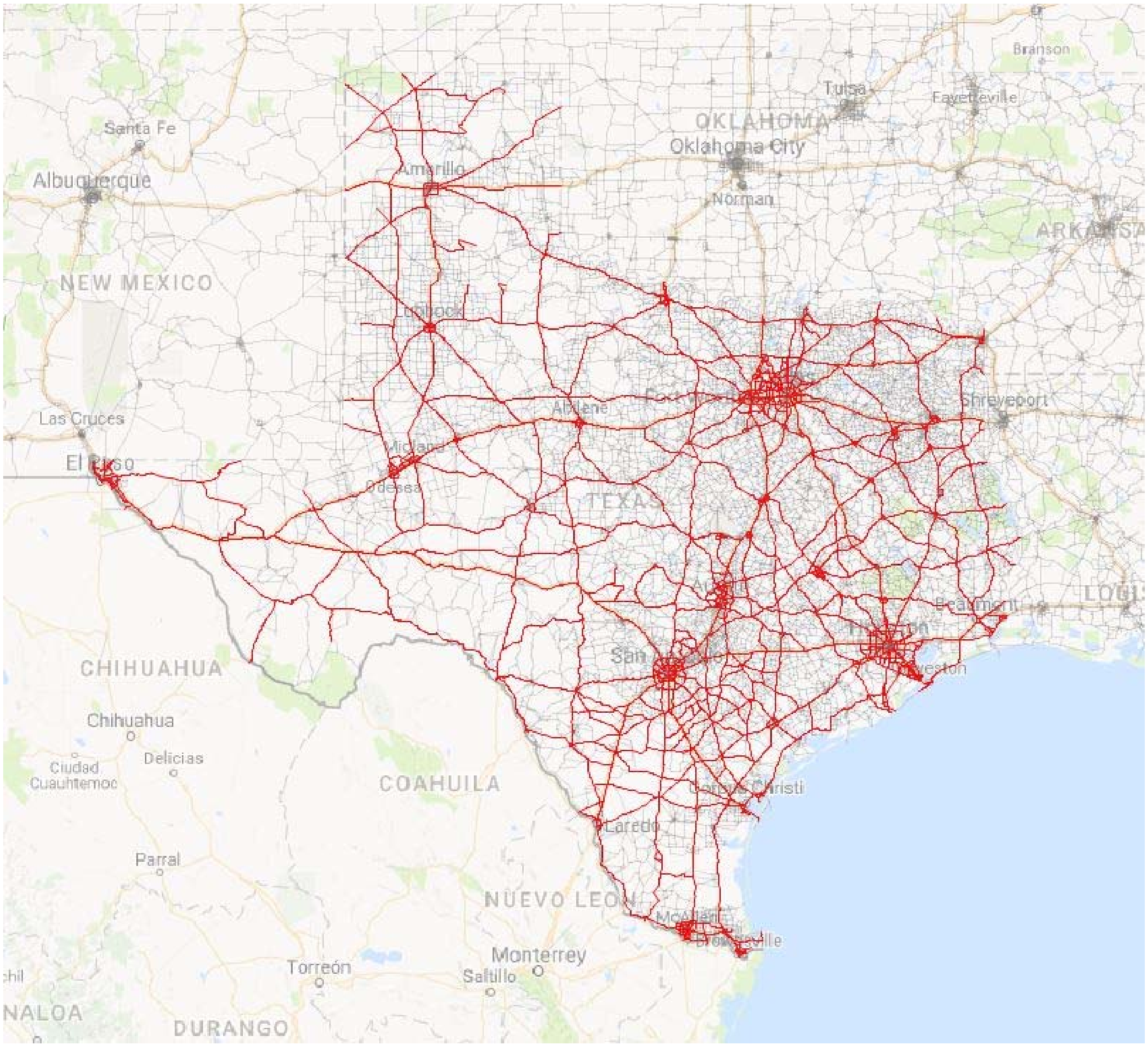


Figure 4.1: Texas Links – Freight Network

Following the selection of all required links within the state of Texas, centroids needed to be added for all Texas counties. The OD and truck trip matrices allocated flow on a county-to-county level. Existing county centroids within SAM were added to the TransCAD freight network and existing centroids from each of the 254 county centroids were manually selected to connect into links already within the TransCAD freight network.

Since some commodities constructed an OD matrix on a state-to-state level (eggs and broiler chickens) while others required use of the most accurate border crossing data (timber and electronics), additional centroids and links needed to be added to the network in order for all commodity OD matrices to be assigned. Border centroids for crossings between Texas and Mexico were manually added based on the data points used in the electronics commodity matrices. Border centroids for crossings between Texas and other states (New Mexico, Oklahoma, Arkansas, and Louisiana) were added based on where the Texas primary and secondary freight networks crossed into and out of the state of Texas. Centroids were added for all other states (except Hawaii) and all SAM interstate highway links outside of Texas were also added to connect to these centroids. As with the Texas county centroids, all additional centroids were manually inspected to determine if a connection existed in the TransCAD freight network. The full scope of the network in the lower forty-eight states is illustrated in Figure 4.2.

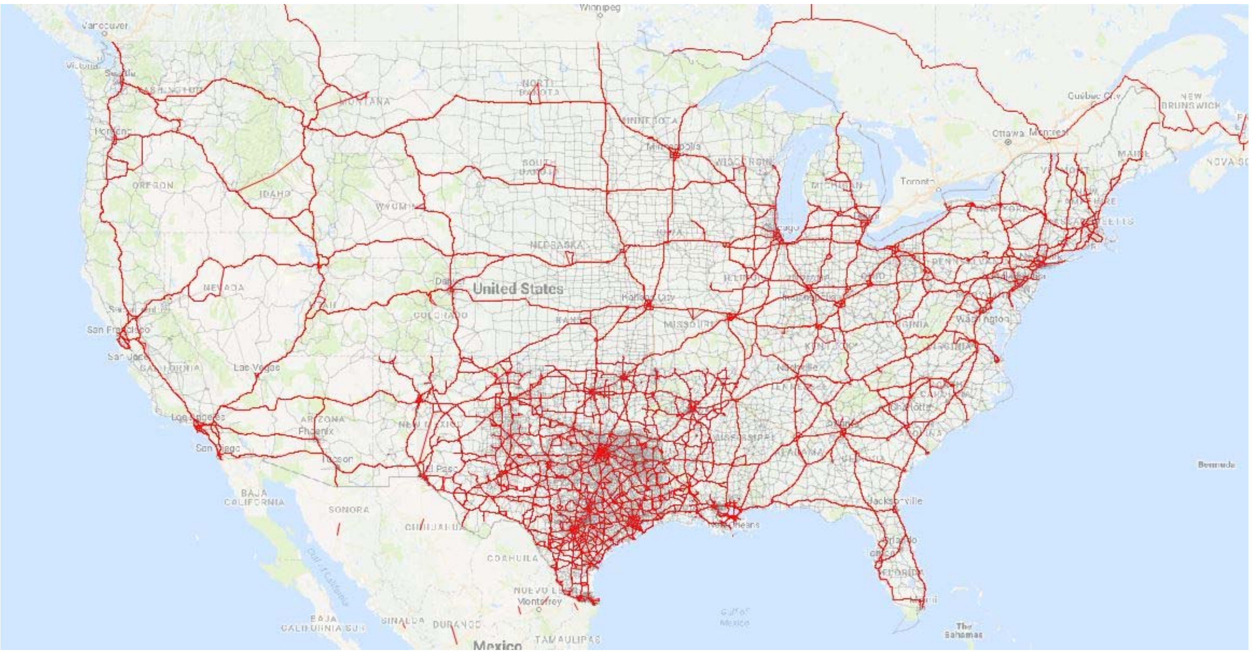


Figure 4.2: All Links – TransCAD Freight Network

The network centroids included in Texas are illustrated in Figure 4.3 while all those included in the network (excluding Alaska) are illustrated in Figure 4.4.

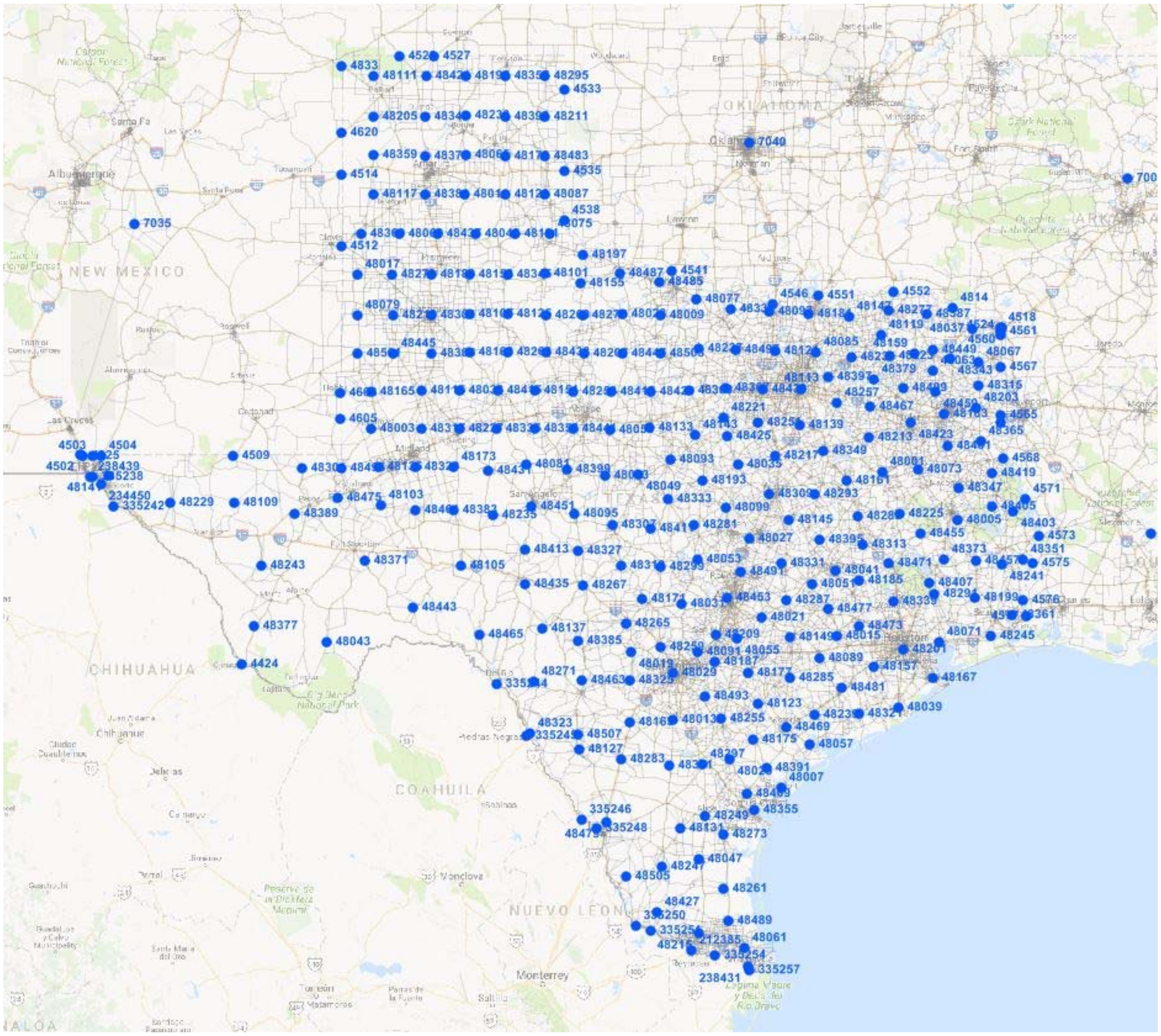


Figure 4.3: Texas Nodes – TransCAD Freight Network

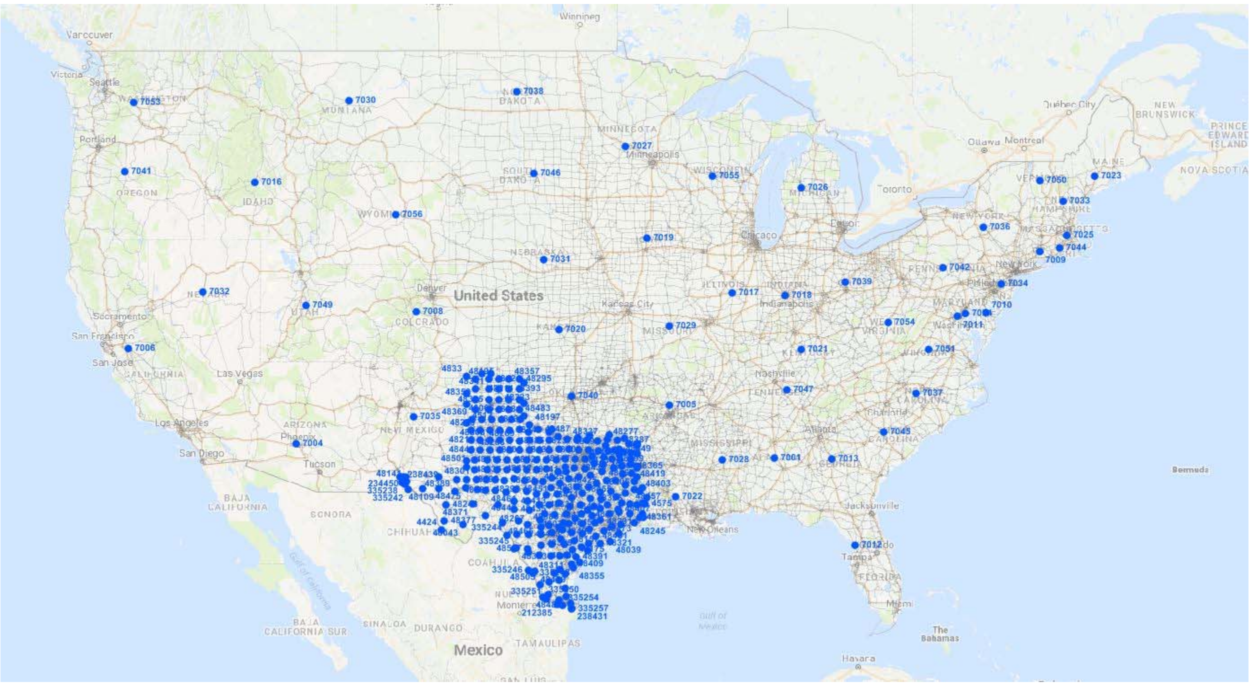


Figure 4.4: All Nodes – TransCAD Freight Network

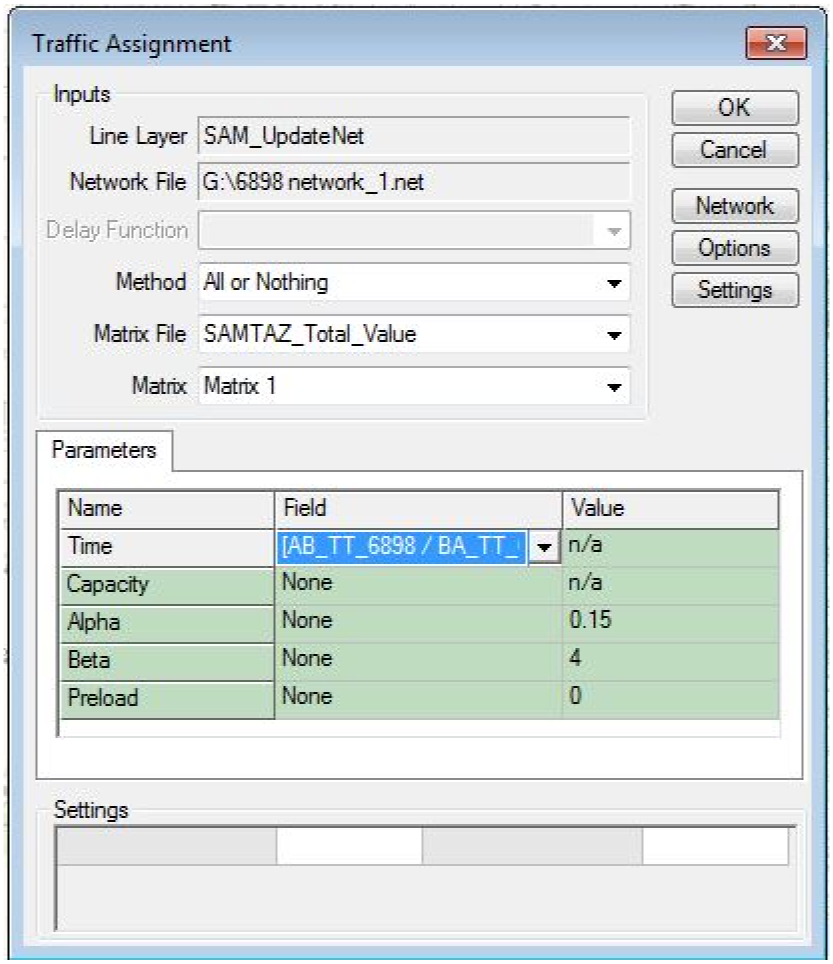
4.3.2 Assignment Procedure

The network includes a total of 352 centroids. For each commodity, the truck trip and value matrices were adjusted to fit into a 352 x 352 matrix template. The matrices were then imported into TransCAD so that an assignment could be run for each type of truck, the total trucks trips (for each commodity), the value of each commodity, and the total value of all commodities studied in this research project. The assignments were run using the Traffic Assignment tool within TransCAD (Figure 4.5).

All truck trip and value flows were allocated using an all-or-nothing assignment to the TransCAD freight network. Free flow travel time in 2010 obtained from the Statewide Analysis Model (SAM) was used to determine the shortest path for an OD pair within the network.

For each commodity, we assigned truck trips and value to the freight network. Though we estimated the number of both loaded and empty truck trips, only loaded trucks were assigned to the network, as only loaded trucks cause high consumption of the road infrastructure.

The assignment results will be discussed in detail in the “Network Analysis” section for each commodity in Chapter 5.



Line Layer: SAM_UpdateNet
Network File: G:\6898 network_1.net
Delay Function:
Method: All or Nothing
Matrix File: SAMTAZ_Total_Value
Matrix: Matrix 1

Name	Field	Value
Time	[AB_TT_6898 / BA_TT_	n/a
Capacity	None	n/a
Alpha	None	0.15
Beta	None	4
Preload	None	0

Figure 4.5: TransCAD Traffic Assignment Tool

4.4 Comparing Estimation Results with Existing Databases

The research team compared the commodity-based truck flow estimation results obtained from network analysis with two other databases: TDMS and Transearch. TDMS data provides the traffic count information at 1269 traffic stations. This traffic count information is used to estimate the number and class of trucks on Texas roadway network. Therefore, TDMS-based link traffic volumes are used to validate the truck trip assignment results produced from network analysis. However, TDMS data do not have any information about commodity type, therefore, it cannot be used to be compared with each commodity individually. Its link-level truck volume can be used as an upper bound to check against the total truck volume we estimated for all the commodities in this project. Chapter 6 discusses details about how TDMS data are processed and the comparison results.

Transearch, an annual database of US county-level freight movement data used for freight modeling and forecasting, is produced by the Trade & Transportation consulting practice within IHS Consulting and Advisory Services. TxDOT purchased 2010 and forecasted 2020 and 2030 Transearch data for the state of Texas. Transearch includes county-to-county flow data for more than 450 individual commodities and 7 modes of transportation. The Transearch database and FAF database are the most widely used commodity flow datasets in transportation planning. However, FAF database does not provide county-to-county level freight flow estimates, so it cannot be used to compare with the county-level commodity flows estimated in this project. The comparison involves examining major discrepancies in modeling results at the OD, truck counts, and the network levels.

4.4.1 Transearch Data

The Transearch database purchased by TxDOT contains commodity flow information within Texas. It includes 2010 base year information and forecasted 2020 and 2030 information. The 2010 database includes 13,677,177 records. Each record has eighteen variables:

- Year – the year of the observation (2010 for the data we used)
- Origin Region – for Texas origins, Transearch uses the Federal Information Processing Standard (FIPS) code of the county of origin. For locations outside Texas, Transearch uses 393 regions. The first 309 regions are parts of US states (or entire states if the state is small enough). The remaining regions correspond to parts of Mexican states, Canadian Provinces, or US territories.
- Destination Region – same as origin region
- STCC – standard transportation commodity codes of the observation. Transearch uses the commodity group and two additional digits.
- Equipment – type of transport method, such as bulk, tank, or livestock transport
- Hazardous Materials – designates whether an observation involves the movement of hazardous materials, and what type
- Trade Type – type of trade movement (e.g., NAFTA, import, export)
- Mode – the mode used for observation (Transearch includes fifteen modes, including four trucking modes)
- Tons – weight moved in the observation, measured in short tons
- Units – truck-units involved in the observation
- Value – dollar value of the goods in the observation
- Average Miles – estimated trip distance
- First Node – coding for Transearch network
- Last Node – coding for Transearch network
- From FIPS – FIPS code of the last county outside Texas, zero for states in Mexico
- To FIPS – FIPS code of the first county outside Texas, zero for states in Mexico
- Entry Road – roadway used to enter Texas
- Exit Road – roadway used to exit Texas

4.4.2 Issues with Comparing to Transearch Data

The primary obstacle in comparing the Transearch data with commodity flow estimates developed in this project was in converting origins and destinations in Transearch to points in the network used in this project. The research team mapped endpoints in Texas counties directly to the created network (see Section 4.3.1). For trips with endpoints in other states, Transearch uses state regions. The research team aggregated these and assigned them all to the same state centroids used in network analysis (see Section 4.3). For endpoints in Mexican states or Canadian provinces, the research team used Transearch's data on entry and exit roads to assign trips to points on the Texas border.

Another issue with comparison is that Transearch uses commodity classifications according to the STCC system. STCC uses seven digits to classify commodities between 38 groups. Transearch records up to four digits, including the two-digit commodity type. Table 4.1 shows how the STCC codes analyzed compare to the commodity categories being investigated.

Table 4.1: Crosswalk of 0-6898 commodities to Transearch STCC codes

0-6898 Commodity	Nearest STCC Code in Transearch	STCC Description
Cattle	01 41	Livestock
Grain Sorghum & Corn	01 13	Grain
Broilers	20 16	Dressed Poultry, Frozen
Eggs	01 52	Poultry Eggs
Gasoline/Fuel Ethanol	29 11	Petroleum Refining Products
Sulphur	28 19	Misc. Indus Inorganic Chemicals
Motor Vehicles	37 11	Motor Vehicles
Timber	24 11	Primary Forest Materials
Electronics	36	Electrical Equipment

The commodity type information contained in Transearch enable it to be compared with our estimation results for each individual commodity, however, for most commodities in this project, the STCC codes used by Transearch are too broad, and include other related commodities. For example, STCC code 01 41 is for all livestock, while this project only analyzed cattle. In Chapter 5, the results of assigning those Transearch commodities shown in Table 4.1 to the freight network created in this project (see Section 4.3.1) and how they compare with the assignment results of commodities studied in this project are discussed in the section "Compare with Transearch Data" for each commodity.

4.5 Incorporating Impact of Seasonal Variation and Congestion

The movement of some commodities can be significantly impacted by the seasonal variation of the commodities' production and consumption. The seasonal estimates can be used to better inform any anticipated changes on the network based on movement of a specific group of commodities. The research team collected data from various datasets that report monthly information of commodity production and/or consumption. This information is used to evaluate whether significant seasonal variation exists for the movement of the commodity and estimate the monthly distribution of the annual truck trips estimated in previous tasks.

In addition to seasonal variation, travel time could impact the freight movement as well. Congested highways might be avoided for local movements. The research team incorporated the impacts of travel time into the commodity flow movement in two ways: 1) travel time can impact the commodity distribution among different OD pairs and 2) travel time can impact the route choice of commodity movements. The first type of impact was considered by using congested OD travel time instead of distance as impedance in the gravity model for distributing commodity flow among OD pairs. The second type of impact was considered by running user equilibrium traffic assignment based on congested link travel time. User equilibrium, compared with all-or-nothing traffic assignment method, will allow truck trips use multiple equally fast routes between an OD pair rather than all truck trips concentrate on one shortest path between that OD pair.

Seasonal variations and travel times are important factors that affect the movement of commodities. This project explores some ways to incorporate these factors into the commodity flow estimation process so that their impacts can be identified and measured. The general procedures of how to identify and measure their impacts are described in this section. The specific results will be discussed for each commodity in Chapter 5.

4.5.1 Overview of the Method of Studying Impact of Commodities' Seasonal Variations

Seasonal variation studies facilitate a deeper understanding of peak, off-peak, and the variations of truck flow in transporting certain commodity types during a year. After incorporating seasonality into commodity flow estimation model, the impact of freight movement on Texas roadways can be better understood.

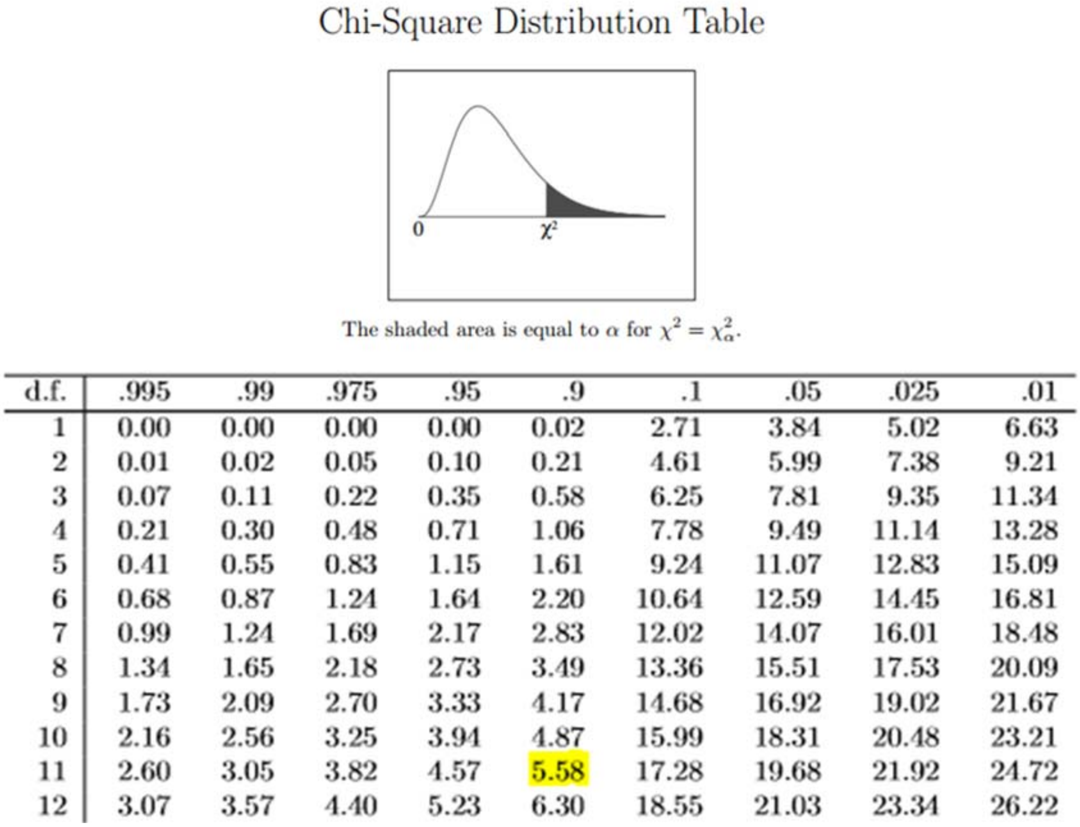
This study of seasonal variations for different commodity types utilizes data from the USDA, US Energy Information Administration, *Trading Economics*, and Transborder databases, etc. The most recently available data for 2015 and 2016 was collected for this study. Commodities that do not experience seasonal variations (as was established during the research team's online data search and conversations with industry representatives), such as fuel ethanol, plastic & rubber, sulphur, and timber, are excluded from this part of the study.

The research team first drew a run sequence plot, which is a graph showing the data in time for each commodity. The seasonal variation of some commodities can be easily identified by observing the plot of monthly percentages. However, for some other commodities, it was not obvious to determine if there was a seasonal variation by just observing the plot. To identify if these commodities do have seasonal variations based on collected data, the research team applied a chi-square test of goodness of fit, which is a useful statistical method for determining whether observations fit the theoretical expectation (McDonald, 2014). The null hypothesis is the monthly percentages are constantly distributed and the alternative hypothesis is the reverse. Then, the chi-square is calculated by using the formula shown below. In this formula, the expected value is the average value of all collected data and observed value is the collected data for each month.

$$X^2 = \sum_{i=1}^{12} \frac{(expected(i) - observed(i))^2}{expected(i)}$$

A ninety percent confidence interval ($\alpha = 0.1$) and degree of freedom is chosen for the hypothesis test. The degree of freedom (d.f.) is (d.f.=n-1). The critical value of chi-square is $X_t^2 =$

5.58 (df=n-1=11, $\alpha = 0.1$). If the estimated chi-square is higher than critical value, the null hypothesis is rejected, which means the commodity has significant seasonal variation. Otherwise, no seasonal variation is assumed for that commodity. See Figure 4.6.



Chi-Square Distribution Table

The shaded area is equal to α for $\chi^2 = \chi^2_\alpha$.

d.f.	.995	.99	.975	.95	.9	.1	.05	.025	.01
1	0.00	0.00	0.00	0.00	0.02	2.71	3.84	5.02	6.63
2	0.01	0.02	0.05	0.10	0.21	4.61	5.99	7.38	9.21
3	0.07	0.11	0.22	0.35	0.58	6.25	7.81	9.35	11.34
4	0.21	0.30	0.48	0.71	1.06	7.78	9.49	11.14	13.28
5	0.41	0.55	0.83	1.15	1.61	9.24	11.07	12.83	15.09
6	0.68	0.87	1.24	1.64	2.20	10.64	12.59	14.45	16.81
7	0.99	1.24	1.69	2.17	2.83	12.02	14.07	16.01	18.48
8	1.34	1.65	2.18	2.73	3.49	13.36	15.51	17.53	20.09
9	1.73	2.09	2.70	3.33	4.17	14.68	16.92	19.02	21.67
10	2.16	2.56	3.25	3.94	4.87	15.99	18.31	20.48	23.21
11	2.60	3.05	3.82	4.57	5.58	17.28	19.68	21.92	24.72
12	3.07	3.57	4.40	5.23	6.30	18.55	21.03	23.34	26.22

Figure 4.6: Chi-square Distribution Table

4.5.2 Overview of the Method of Studying Impact of Congestion

The goal of this part of study was to explore ways to incorporate the impacts of travel time into the commodity flow estimation process and develop methods to measure these impacts. The research team considered the impacts of travel time to the following two steps of the modeling process: 1) trip distribution and 2) traffic assignment.

Impact of Travel Times on Trip Distribution

Gravity model is a classic method used for distributing commodity productions and attractions among different OD pairs. The research team used this method for developing the original OD matrices for several commodities (see “Commodity Flow Estimation” section for each commodity in Chapter 5). However, the impedance used in those gravity models is the distance between origins and destinations. This distance can reflect the level of closeness of different OD pairs but not the real travel impedance between those OD pairs. Therefore, to take into consideration the impact of travel times on trip distribution, the research team obtained congested OD travel times from SAM and updated the OD matrices of those commodities where a distance-based gravity model was originally used.

SAM model 2010 and 2020 scenarios were run. PM peak link travel times and OD travel times from these two scenarios were obtained. Link travel times and OD travel times of intermediate years between 2010 and 2020 were estimated through linear interpolation. Different years' travel times were needed because different commodities used data sources from different years to estimate productions and attractions; therefore, it is more accurate to use the same year's travel time to distribute productions and attractions.

When OD matrices were originally developed, the following commodities used a distance-based gravity model:

- Broilers
- Eggs
- Corn (farms to elevators)
- Grain sorghum (farms to elevators)
- Corn and grain sorghum (elevators to feed yards)
- Motor vehicles
- Timer
- Gasoline

For these commodities, the corresponding year's OD travel times replaced the distance used as the impedance in the gravity model. In this way, the distribution of these commodity productions and attractions takes into consideration the impact of travel time. Updated truck trip and value matrices of these commodities are included in the Appendix 2 of the report.

For some other commodities, such as cattle and electronics, the research team did not use the distance-based gravity model in the trip distribution step for one of two reasons: either 1) the original OD matrices' development already took into consideration the impact of travel time, or 2) travel time does not have an impact on the distribution based on information gathered online or from talking with industry representatives. For details of how the distribution was done for these commodities, please refer to the "Commodity Flow Estimation" section for each commodity in Chapter 5.

Impact of Travel Times on Traffic Assignment

Travel times can also impact freight vehicles' route choices. When one route is known to be congested, commodity shippers may choose to switch to another route to reduce their travel time until there are no other routes that have shorter travel times. This route choice behavior is well captured by the User Equilibrium traffic assignment. The all-or-nothing traffic assignment method used in the original network analysis, however, only assign all the vehicles to the shortest route, even this may cause this shortest route to become very congested and much slower than many other unused routes. The all-or-nothing traffic assignment method describes a vehicle's route choice behavior when there is not much congestion on the road network, because in that case, even all vehicles choose the same route, that route will still be the shortest one. However, this is not practical when the network is congested. Based on this consideration, the research team performed a new network analysis with User Equilibrium traffic assignment method for all the commodities using congested link travel time.

Similar to OD travel times, link travel times are also obtained after running SAM 2010 and 2020 scenarios. PM peak travel times are used to reflect the most congested condition. Link capacities used for the traffic assignment are also obtained from SAM model. The link capacities used for the traffic assignment are 24-hour capacities. Therefore, the annual truck trips were converted to daily truck trips (refer to section "Daily Truck Trip Assignment" for each commodity in Chapter 5 for more details about how this is done). The Bureau of Public Roads function was used as the delay function and User Equilibrium BFW (Bi-conjugate Frank-Wolfe) assignment method was selected. This congested travel time based traffic assignment was done for each commodity. The results of the traffic assignment are presented in the section "Daily Truck Trip Assignment" for each commodity in Chapter 5.

4.5.3 Calculating Daily Truck Trips

Daily truck trips were calculated based on the updated OD matrices and the results of the seasonal variation study. For commodities that are identified with significant seasonal variations, daily truck trips in the peak month (the month with highest number of truck movement based on our analysis) were calculated by multiplying the estimated annual truck trips (from the updated OD matrices) by the peak month percentage obtained from seasonal variation and then divided by the number of working days in that month. For commodities without seasonal variation, the daily truck trips were obtained by dividing the annual truck trips by 295, the annualized factor listed in the SAM manual.

The calculated daily truck trips were then assigned to the network using the method described in the previous section. The assignment results therefore incorporated both the impact of seasonal variation (for commodities identified with significant seasonal variation) and the impact of congestion. These results will be discussed for each commodity in the section "Daily Truck Trip assignment" in Chapter 5.

Chapter 5. Commodity-Specific Analysis

In this chapter, the flow estimation process and estimation results for each selected commodity will be presented. For each commodity, this report demonstrate how each of following steps is performed and what the results are.

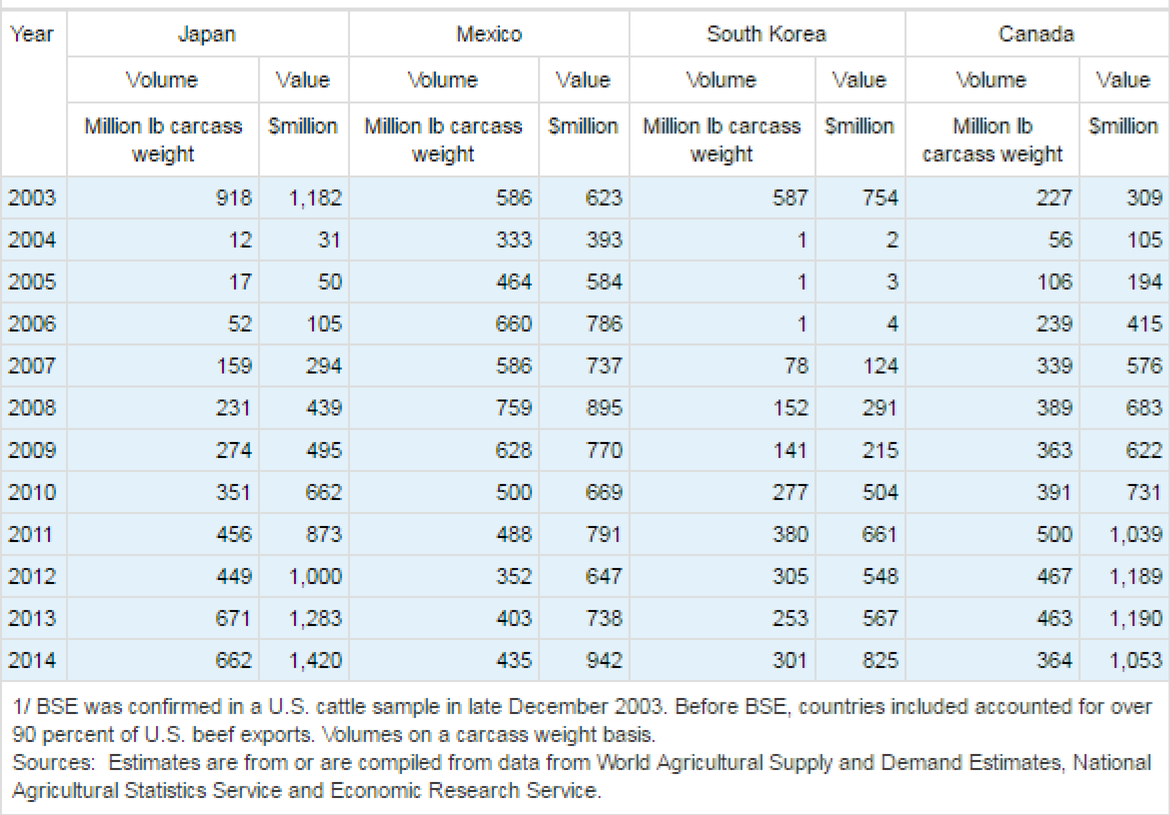
- Data sources identification
- OD flows creation
- Transportation/truck types identification
- Unit value estimation
- Traffic assignment
- Results comparison
- Seasonal variation and daily truck trip estimation

5.1 Cattle

5.1.1 Background

The cattle industry in Texas remains the top agricultural commodity for the state and the per capita consumption of beef outside the US, in countries like Japan, has increased, reflected in the higher beef exports (Table 5.1).

Table 5.1: Top export markets for US beef (USDA, 2016)



Year	Japan		Mexico		South Korea		Canada	
	Volume	Value	Volume	Value	Volume	Value	Volume	Value
	Million lb carcass weight	$million	Million lb carcass weight	$million	Million lb carcass weight	$million	Million lb carcass weight	$million
2003	918	1,182	586	623	587	754	227	309
2004	12	31	333	393	1	2	56	105
2005	17	50	464	584	1	3	106	194
2006	52	105	660	786	1	4	239	415
2007	159	294	586	737	78	124	339	576
2008	231	439	759	895	152	291	389	683
2009	274	495	628	770	141	215	363	622
2010	351	662	500	669	277	504	391	731
2011	456	873	488	791	380	661	500	1,039
2012	449	1,000	352	647	305	548	467	1,189
2013	671	1,283	403	738	253	567	463	1,190
2014	662	1,420	435	942	301	825	364	1,053

1/ BSE was confirmed in a U.S. cattle sample in late December 2003. Before BSE, countries included accounted for over 90 percent of U.S. beef exports. Volumes on a carcass weight basis.
Sources: Estimates are from or are compiled from data from World Agricultural Supply and Demand Estimates, National Agricultural Statistics Service and Economic Research Service.

Though Texas cattle inventory has declined since 2007 (Figure 5.1), the following statistics attest to the significance of the cattle industry to Texas (Cook, 2016):

- Texas has the 14th largest cattle inventory in the world.
- Texas accounts for 15.5% of the cash receipts for cattle in the United States. Texas and Nebraska are the only two states with about $10 billion in cash receipts for cattle.

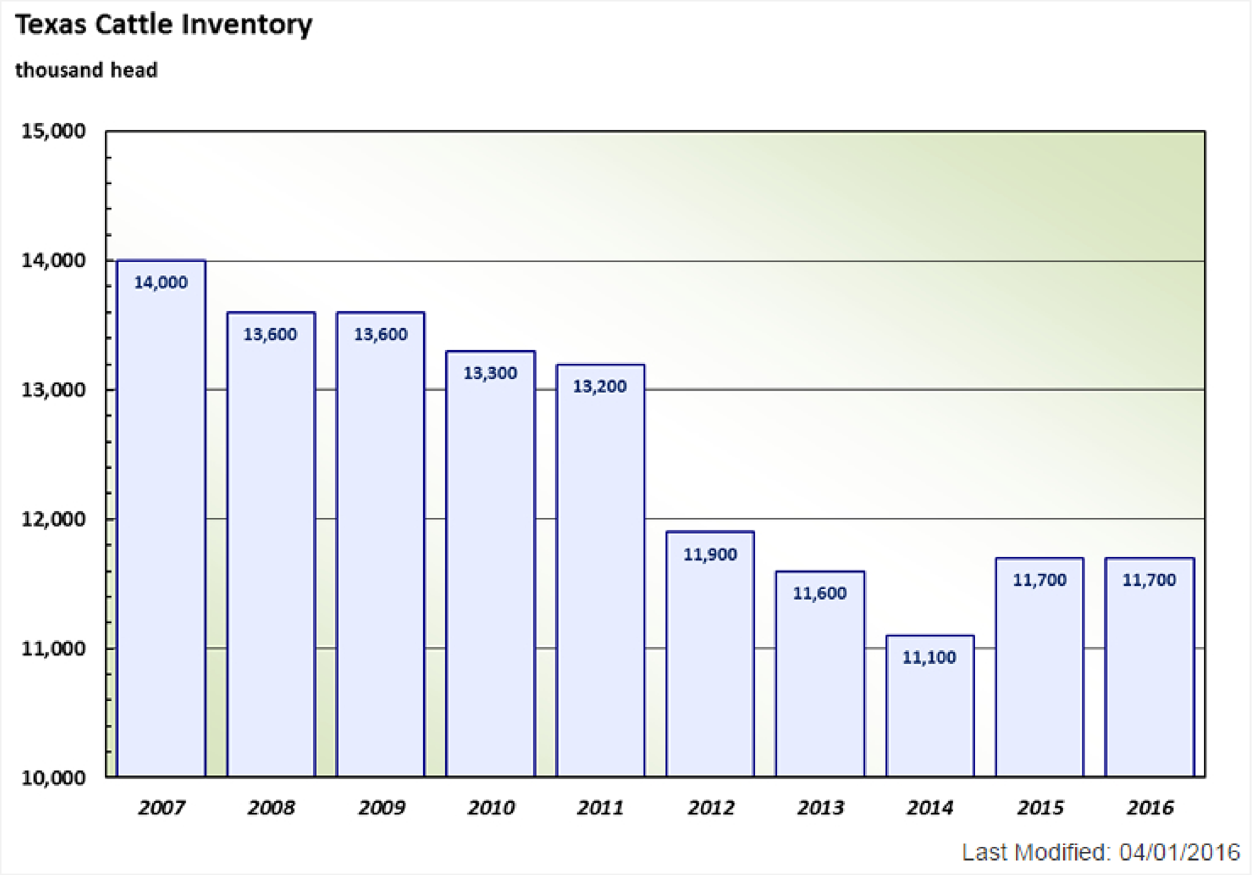


Figure 5.1: Texas Cattle Inventory 2007–2016 (USDA, 2016)

The cattle inventory consists of cattle in different stages of the supply chain.

Cow-calf operations exist on ranges and pastures, using very little supplemental feed. In Texas, the majority of cow-calf operations are in the central and east parts of Texas because of favorable rainfall and temperatures.

Calves remain at these operations until weaned. From there the vast majority eventually make their way to the cattle feedyards, where they are called feeder cattle, or feeders (exceptions are grass-fed cattle, a market niche). The feeding period can last anywhere from 90 days to 300 days. For the feeders, average gain is 2.5 to 4 pounds per day, which requires about 6 pounds of dry-weight feed per pound of gain (USDA, 2016).

Cattle that stay behind to reproduce more cattle are usually called steers, heifers, and beef cows.

5.1.2 Supply Chain

The supply chain options for cattle can include a number of intermediate facilities (e.g., auction sites and order buyer yards as shown in Figure 5.2) or a more straightforward ranch-to-feedyard route. Big ranches will bypass auction houses and order buyers and just send cattle directly to feedyards. For all links, trucks are used to transport cattle (rail no longer is used).

In speaking with representatives of the cattle industry, the number of cattle entering each supply chain option is unknown, and so estimating the flow of cattle starting from the ranch proves difficult. The link of the supply chain from feedyards to slaughterhouses, however, offers more certainty to estimate flow between those two because of the data available. Despite difficulties in modeling full supply chain, the datasets explored and the datasets used for the estimation of movement from feedyards to slaughterhouses are included in the next section.

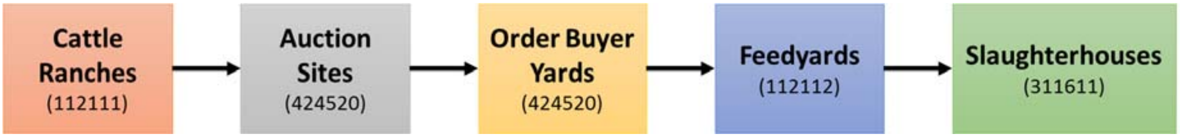


Figure 5.2: Cattle Supply Chains[6]

5.1.3 Datasets

Cattle Ranches

The 2013 Texas Workforce Commission (TWC) data lists 2,689 ranches in Texas under North American Industry Classification System (NAICS) code 112111 and only lists the address associated for the ranch (which may not be the ranch location) and the number of employees. The other concern with the 2013 TWC data is that the *Texas Freight Mobility Plan* pointed out that in the cattle industry in Texas, less than one-third of cattle operators claim farming as their primary occupation, therefore most likely not reported in the TWC data. As stated in earlier, a commodity flow model that relies on reported employment for all industries for estimating commodity generation would not provide an accurate result for an industry such as the cattle industry.

The USDA's National Agricultural Statistics Service (NASS) reports the number of cattle in each county in the following categories:

- All cattle and calves (includes bulls, heifers, and steers for beef and milk cows, calves and replacement milk heifers for dairy)
- Beef cows
- Milk cows

The number of head of cattle and cows by county provides a good foundation for a commodity flow estimation method. However, as described in the next section, identifying which supply chain the cattle follow is difficult to ascertain, except once the cattle get to the feedyards, where data on capacity and location provide an idea of the number of cattle going through that link of the supply chain to the slaughterhouse.

A key thing to notice looking at the two maps for beef cows (Figure 5.3) and all cattle and calves (Figure 5.4) is that the beef cows are primarily in the central and east part of the state, whereas all cattle and calves (which includes the feedyard cattle) are primarily in the Texas Panhandle. The flow of cattle generally is from the ranches of central-east Texas to the Texas Panhandle (with the exception of movement of cattle from smaller feedyards in south Texas to a slaughterhouse in Corpus Christi).

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[6] The number in parenthesis shown in supply chain figures are corresponding NAICS code of supply chain facilities.

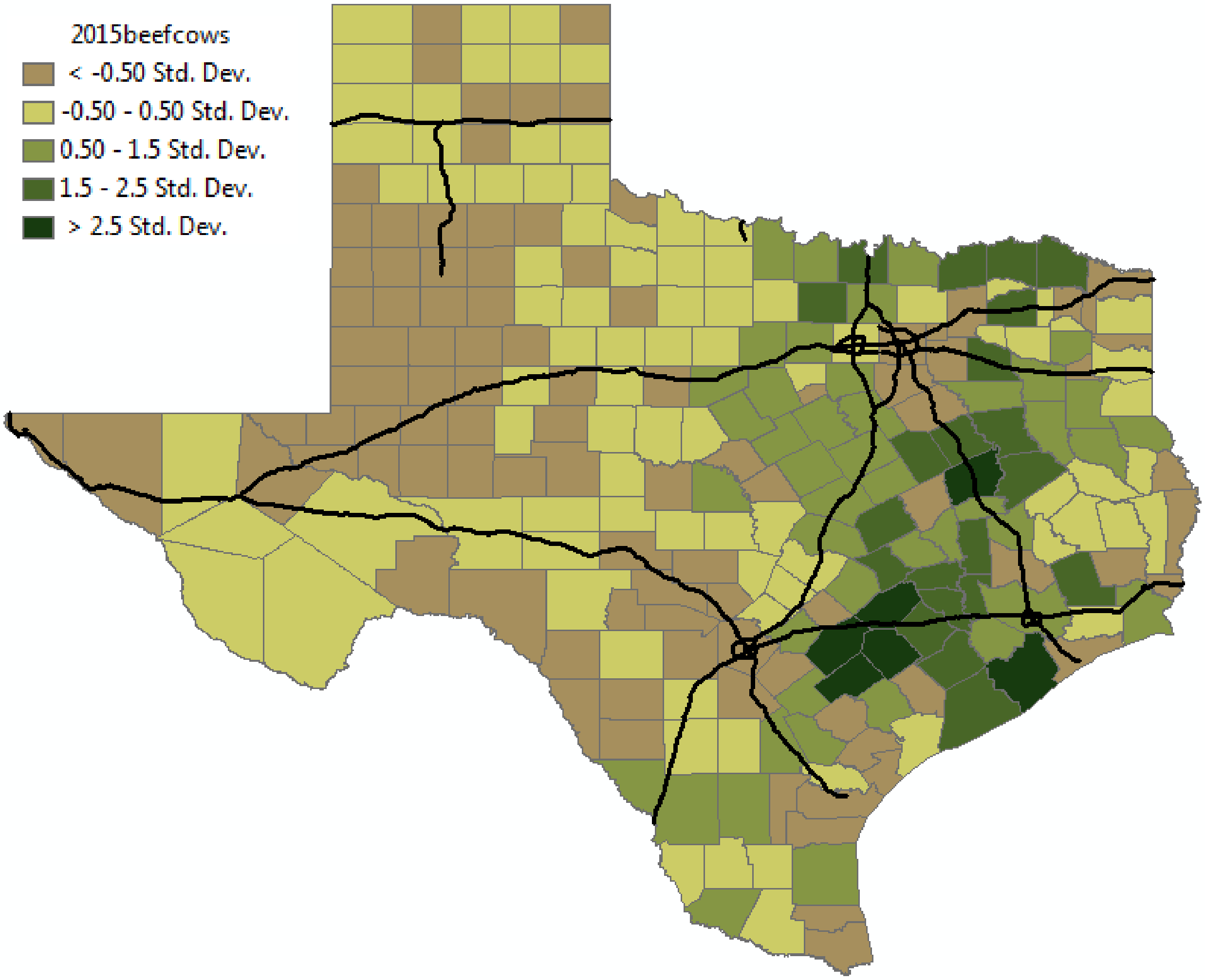


Figure 5.3: Beef Cows 2015 (USDA)

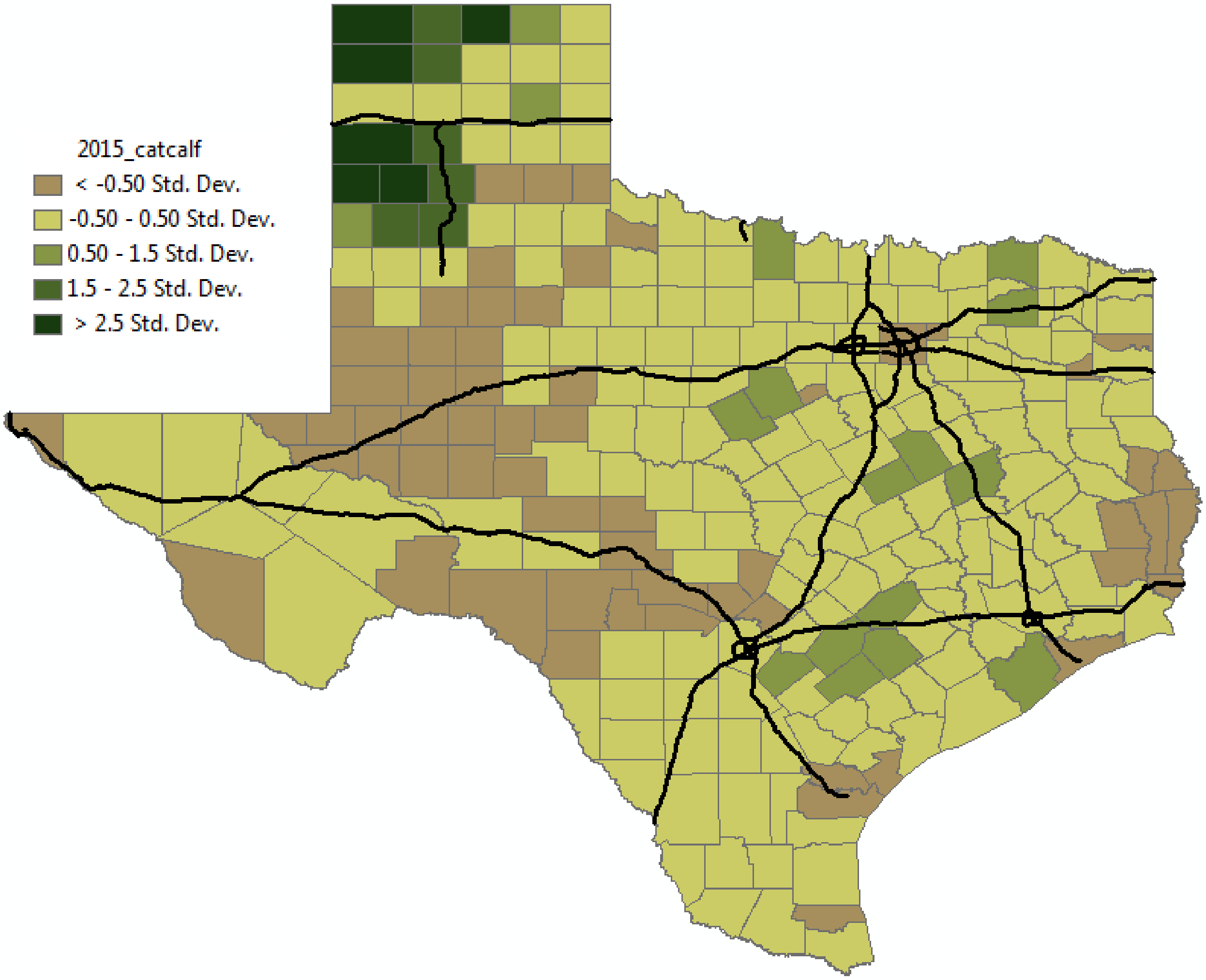


Figure 5.4: All Cattle and Calves 2015 (USDA)

Cattle are brought in from Canada and Mexico into the state; however, since the emphasis is on the feedyard-to-slaughterhouse movement for commodity flow estimation, that flow is not estimated.

Auction Houses, Cattle Dealerships, and Order-Buyer Yards

Ranchers can send their cattle directly to feedyards or send them to auction houses, cattle dealerships, or order-buyers, which are intermediate places in the supply chain to buy and sell cattle. Figure 5.5 shows the 2013 TWC data's listing of auction houses in Texas.

The Texas Livestock Marketing Association (TLMA), the Texas Department of Agriculture (TDA), and the USDA's Grain Inspection, Packers, and Stockyards Administration (GIPSA) all also offer a listing of auction houses in Texas. The GIPSA data source also includes a list of dealers and order buyers. However, the problem with the GIPSA data is that it is not easy to discern which of the dealers and order buyers have actual yards to hold cattle (as opposed to just being offices). That would require a review of each listing and there are over hundreds listed for Texas.

The Texas Animal Health Commission (TAHC) provides calendar year livestock market reports on all cattle sold at approved livestock markets (see Table 5.2 for excerpt of 2015 report). The reports provide the number of head sold at the market and not the type of cattle, which leaves out a detail that provides for a more refined estimate of cattle flow. However, future commodity flow estimation efforts could try to use the livestock market reports to estimate the movement of cattle on the supply chain links ending and starting at livestock auctions.

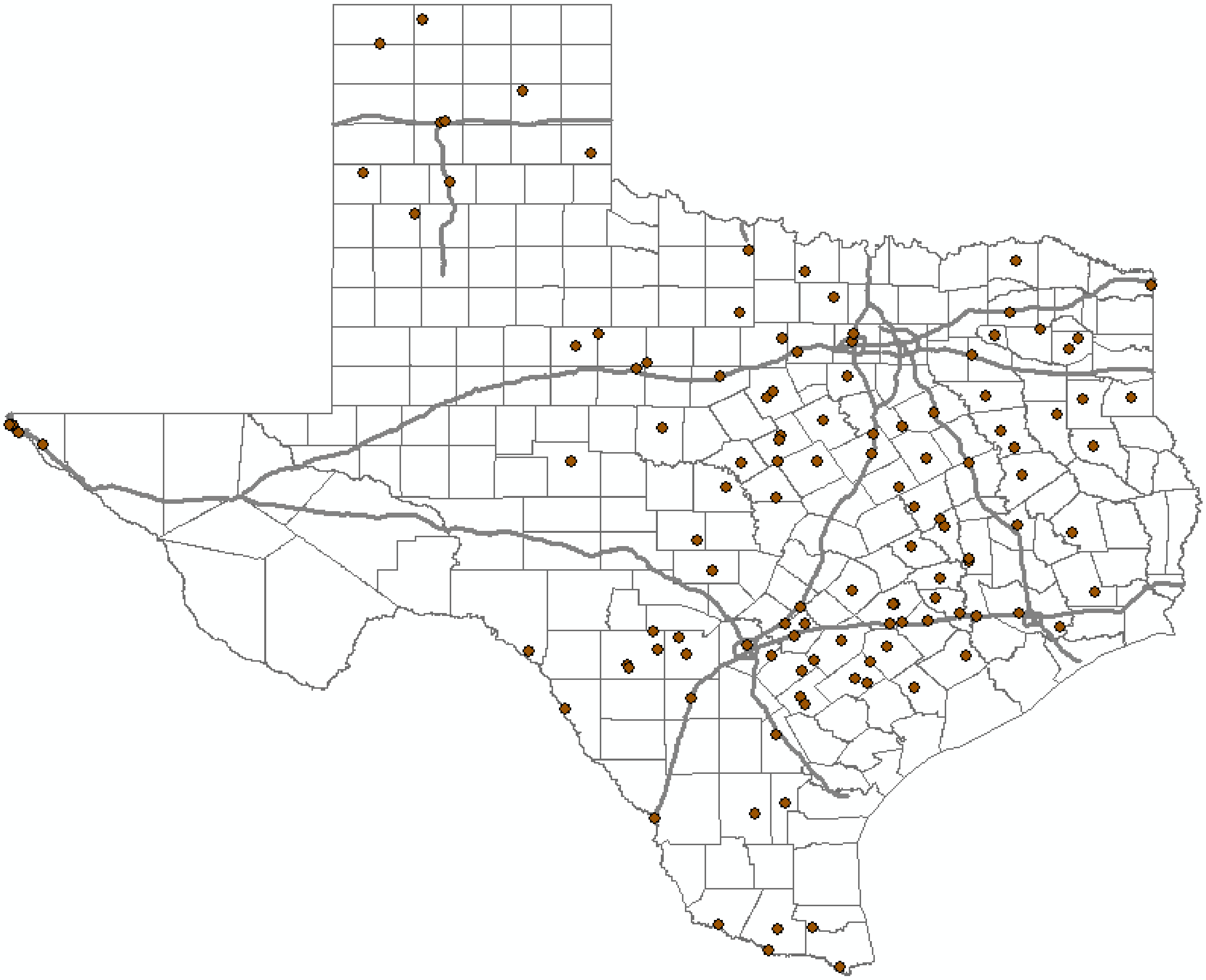
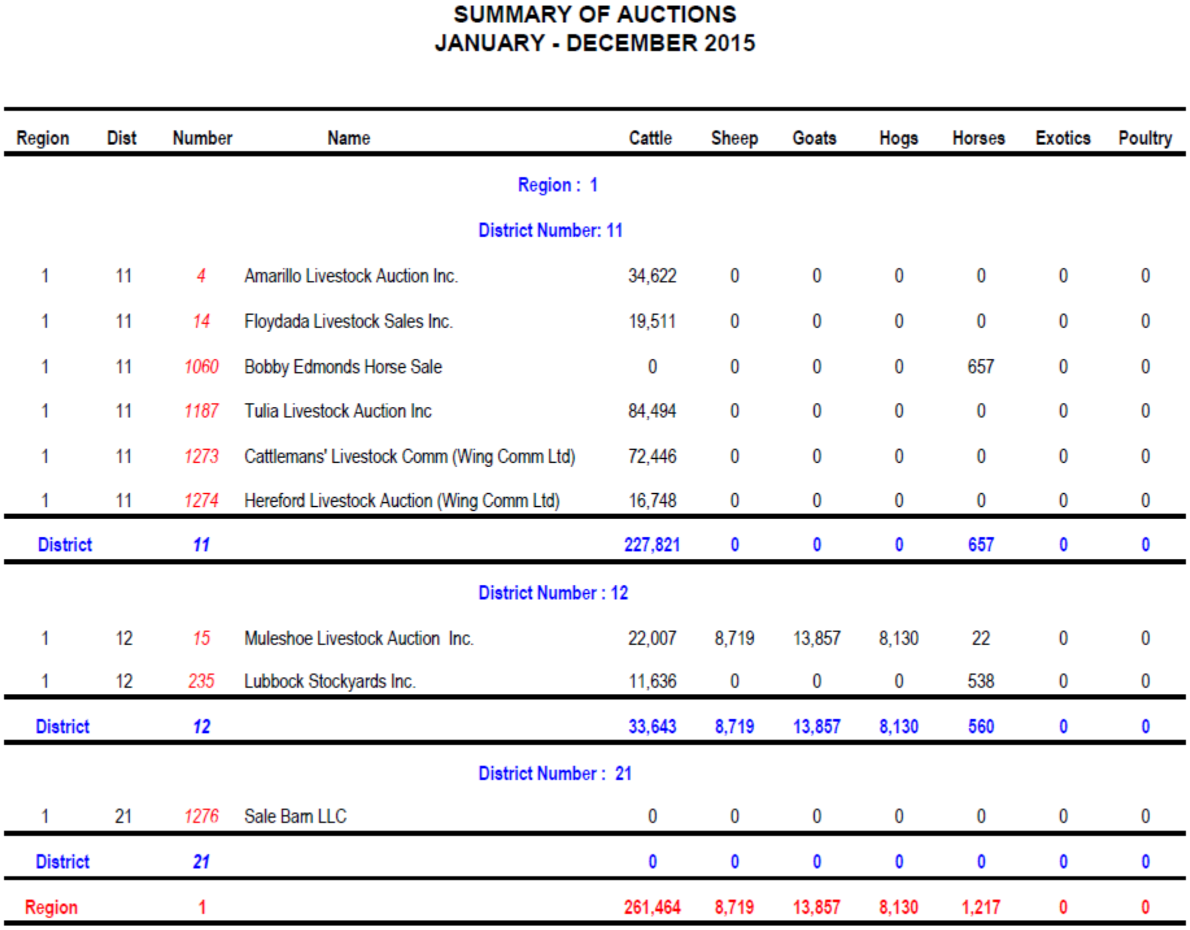


Figure 5.5: 2013 TWC Auction Houses

Table 5.2: Excerpt of Livestock Auction Market Report from TAHC



SUMMARY OF AUCTIONS
JANUARY - DECEMBER 2015

Region	Dist	Number	Name	Cattle	Sheep	Goats	Hogs	Horses	Exotics	Poultry
Region : 1										
District Number: 11										
1	11	4	Amarillo Livestock Auction Inc.	34,622	0	0	0	0	0	0
1	11	14	Floydada Livestock Sales Inc.	19,511	0	0	0	0	0	0
1	11	1060	Bobby Edmonds Horse Sale	0	0	0	0	657	0	0
1	11	1187	Tulia Livestock Auction Inc	84,494	0	0	0	0	0	0
1	11	1273	Cattlemans' Livestock Comm (Wing Comm Ltd)	72,446	0	0	0	0	0	0
1	11	1274	Hereford Livestock Auction (Wing Comm Ltd)	16,748	0	0	0	0	0	0
District		**11**		**227,821**	**0**	**0**	**0**	**657**	**0**	**0**
District Number : 12										
1	12	15	Muleshoe Livestock Auction Inc.	22,007	8,719	13,857	8,130	22	0	0
1	12	235	Lubbock Stockyards Inc.	11,636	0	0	0	538	0	0
District		**12**		**33,643**	**8,719**	**13,857**	**8,130**	**560**	**0**	**0**
District Number : 21										
1	21	1276	Sale Barn LLC	0	0	0	0	0	0	0
District		**21**		**0**	**0**	**0**	**0**	**0**	**0**	**0**
Region		**1**		**261,464**	**8,719**	**13,857**	**8,130**	**1,217**	**0**	**0**

Feedyards

Several data sources provide listings of the feedyards in Texas. The 2013 TWC data contains a listing of businesses with NAICS code 112112, the location, and the number of employees. The Texas Cattle Feeder's Association (TCFA) maintains a feedyard directory that lists every feedyard in Texas except four or five of the major ones according to the director of government relations (since the feedyard directory is of the members of TCFA). The Cattle Trader Center website also lists feedyards. Both the TCFA and Cattle Trader Center data only provide the addresses of the feedyards and no other information.

Lastly, and the one used for this research, is a data source available from the Texas Commission on Environmental Quality (TCEQ) that consists of the concentrated animal feeding operation (CAFO) permits. CAFOs require either general or individual permits from TCEQ for water quality reasons. The TCEQ website offers a way to search for those permits for cattle feedyards and dairy operations. The TCEQ permit data provides the maximum capacity and the latitude and longitude of the feedyard. The capacity of the feedyard informs the number of cattle going to slaughterhouses. The search results are not provided in Excel format, so the results either have to be copied and pasted into Excel, or a code written to pull multiple pages of the search results into an Excel file. Figure 5.6 shows the location of the cattle feedyards from the TCEQ permit database and from the 2013 TWC data. The two datasets differ in number and location of feedyards, but TCEQ data was chosen because feedyards are required to obtain permits and the data includes the feedyard capacity (TWC only contains number of employees).

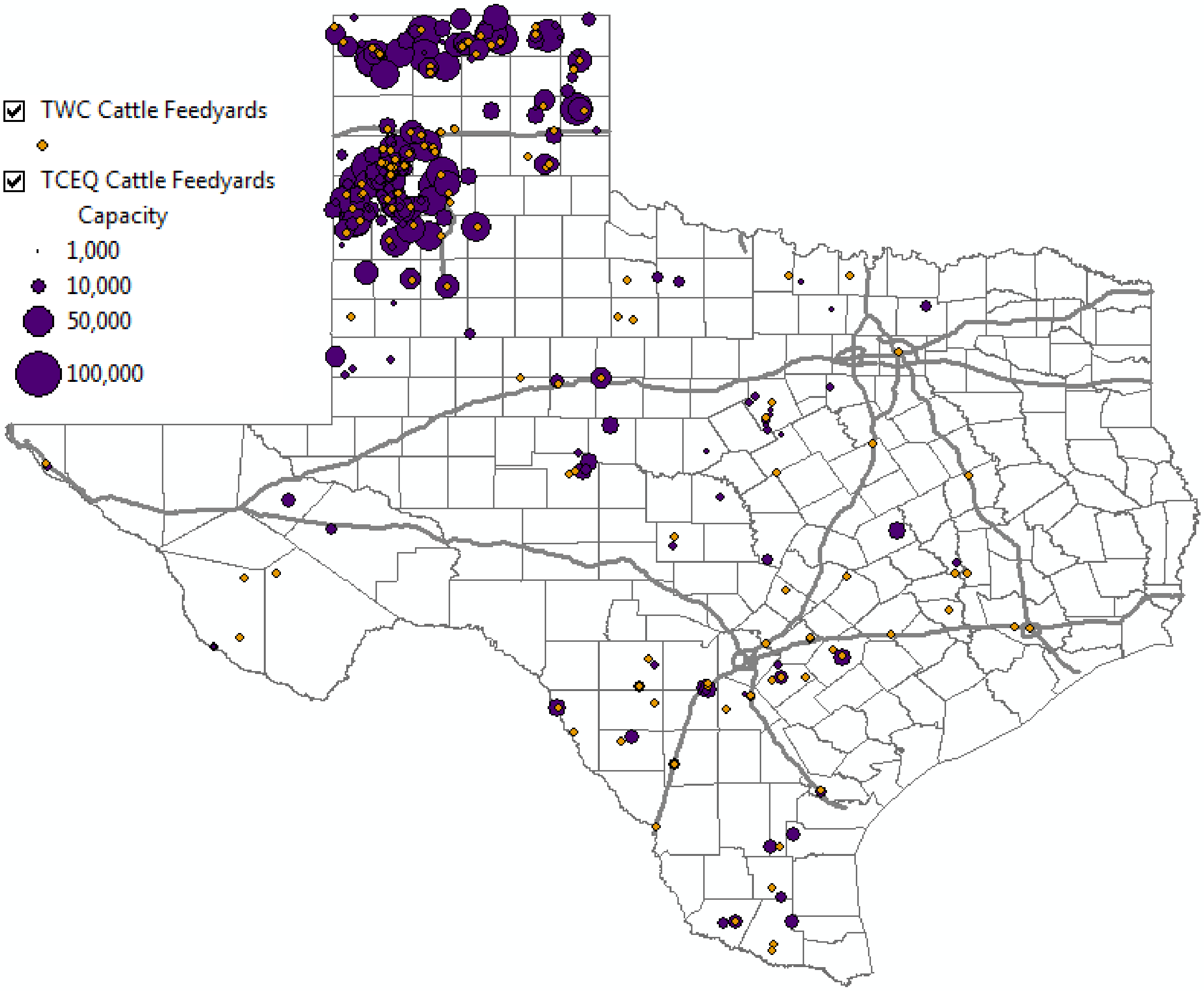


Figure 5.6: TCEQ and TWC Cattle Feedyards

Slaughterhouses

In interviews with representatives of the cattle industry, the research team learned of the different types of slaughterhouses for different types of meat and cows. Older cows, such as those from the dairy industry and some beef cows, will go from the ranch to slaughter facilities for hamburger meat. Those older cows do not go to the feedyards, so those types of slaughter facilities are not included in the model, since the focus is on the supply chain link between the feedyards and slaughterhouses. Therefore, when reviewing datasets for slaughterhouses, in addition to checking for animal type, the process also requires narrowing the list down to those that only process cattle from feedyards.

As with feedyards, multiple data sources provide listings of the slaughterhouses in Texas. The 2013 TWC data lists 105 animal slaughtering (except poultry) businesses with NAICS code 311611 with their location and number of employees. The USDA Food Safety and Inspection Service (FSIS) provides a listing of all the federally inspected slaughter, processing, and warehousing facilities and their locations only (but no other supporting data such as number of employees, capacity, or sales). For slaughterhouses, the USDA FSIS lists 53 in Texas, which includes non-beef facilities, such as chicken slaughter. The Texas Department of State Health Services Meat Safety Assurance Unit (MSAU) lists the establishments that receive full inspections. The listing of 174 businesses gives the addresses of the facility, but no other information useful for commodity flow estimation and appear not to be for the types of slaughterhouses processing feeders. The TCFA lists packing companies in their services directory, but since the listing is of members, there are very few: 13. The TWC and MSAU datasets have many more businesses listed because they are including smaller establishments that include some animal slaughtering. For purposes of this research, the interest is on the larger slaughterhouses.

A dataset from the USDA's GISPA lists the packing plants in Texas and includes the location and bond amount held by each facility (Table 5.3) (USDA GIPSA, 2016). According to a representative of the TLMA, the bond amount gives an indication of the capacity of the slaughterhouse. The bond amounts range from $10,000 to a high of $4,715,000. The top two are slaughterhouses that process feedyard cattle. Facilities like Lone Star Beef are for hamburger meat, which do not come from feeders. However, the list is not complete since there are some large slaughterhouses, such as the JBS slaughterhouse facility in Cactus, Texas, that handle billions of dollars of livestock slaughter.

Table 5.3: GIPSA listing of packing plants

Business Name	City	Zip code	Bond Amount ($)
Caviness Beef Packers Ltd.	Amarillo	79120	4,715,000
Sam Kane Beef Processors, LLC	Corpus Christi	78469	3,500,000
Lone Star Beef Processors, L.P.	San Angelo	76903	2,670,000
Preferred Beef Group, LP	Booker	79005	2,060,000
Beyer & Funderburgh Ltd.	Dublin	76446	455,000
H & B Packing Co., Inc.	Waco	76703	440,000
American Homestead Natural Pork, LLC	Vernon	76385	265,000
Beltex Corporation	Fort Worth	76106	260,000
J & J Packing Co., Inc.	Brookshire	77423	120,000
Columbia Packing Co., Inc.	Dallas	75339	70,000
J & B Livestock, LLC	Mason	76856	45,000
Glen's Packing Company, Inc.	Hallettsville	77964	40,000
Mills County Meat Company, Inc.	Goldthwaite	76844	40,000
Cabritos Garza Inc.	Humble	77338	35,000
Fisher Meat & Processing Center, Inc.	Spring	77379	35,000
Harris, Samuel Wayne II	Houston	77039	25,000
Prime Fresh Foods LLC	Goldthwaite	76844	20,000
Mineola Packing Co., Inc.	Mineola	75773	15,000
Alpas LLC	Houston	77025	10,000
Kasper Meat Market, Inc.	Weimar	78962	10,000
Ray Foods LLC	Poth	78147	10,000

TCFA indicated there are really five slaughterhouses in Texas doing the bulk of the slaughter of cattle from feedyards (orange dots in Figure 5.7):

- Sam Kane Beef Processors in Corpus Christi
- Caviness in Hereford
- Cargill in Friona
- JBS in Cactus
- Tyson Fresh Meats (formerly IBP)[7] in Amarillo

The Cargill, JBS, and Tyson slaughterhouses appear in the USDA directory. All except JBS appear in the TWC data. Not all cattle that enter the slaughterhouses come from feedyards, however, so another piece of information needed is the percentage of cattle going to the slaughterhouse from feedyards. For purposes of initial commodity flow estimation, it will be assumed that all cattle going into the five packing plants selected for this research come from the feedyards with the TCEQ permits, which is most likely the case.

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[7] IBP, Inc., formerly known as Iowa Beef Processors, Inc., is now Tyson Fresh Meats.

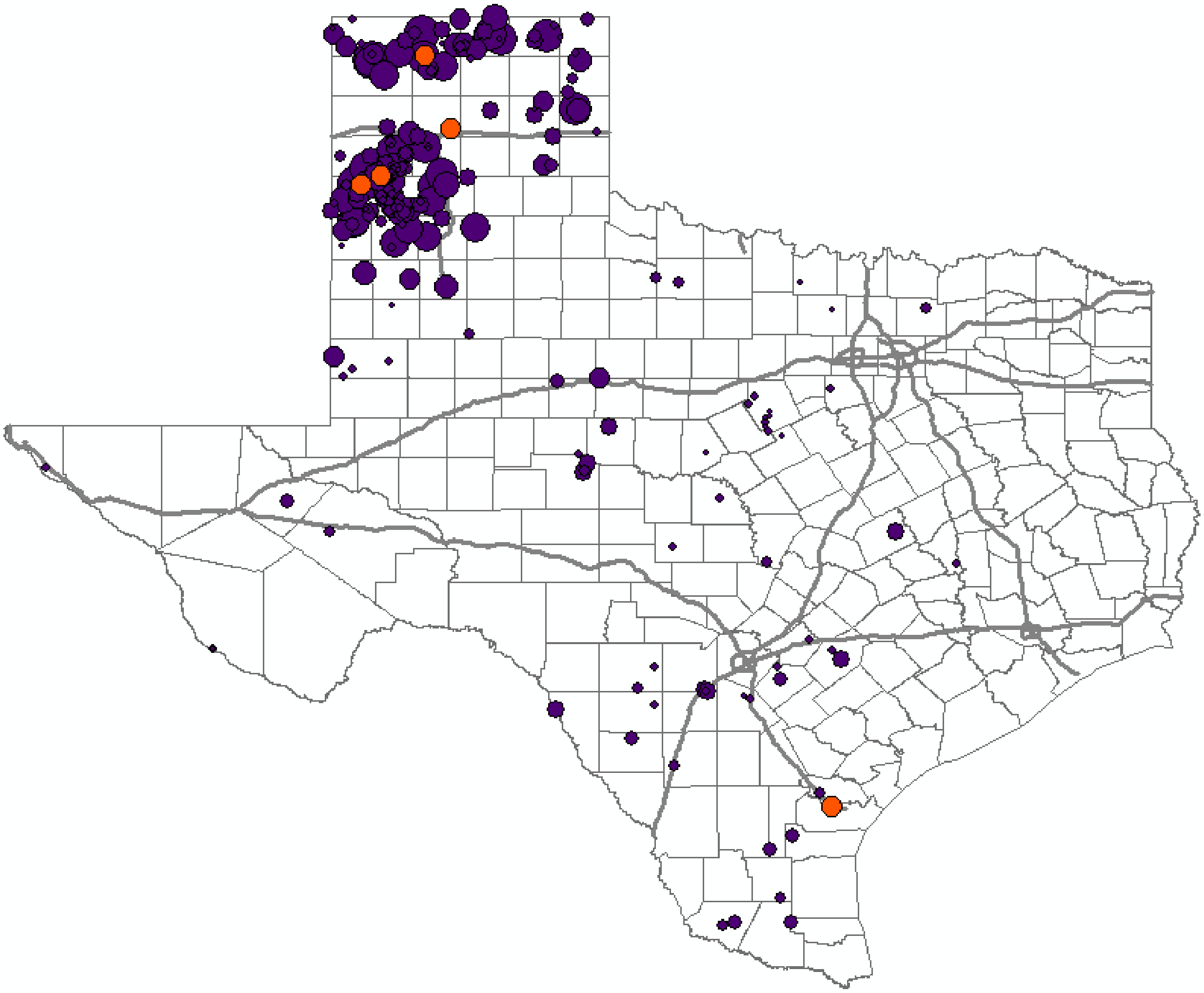

Figure 5.7: Map of Five Large Slaughterhouses (orange dots) and TCEQ-permitted Feedyards (purple dots)

Interviews with cattle industry representatives and articles about the industry indicate that some feedyards and slaughterhouses are vertically integrated. Those types of business structures make modeling the commodity flow with traditional models, like gravity model, to distribute cattle from feedyards to slaughterhouses, less feasible. Therefore, vertical integration is identified up front through discussions with industry representatives and articles and OD flows assigned according to the vertical integration, which in some cases means cattle are moved to a slaughterhouse located farther away than a slaughterhouse closer to the feedyard. Known vertical integration includes:

- Cactus feedyard cattle go to the Tyson packing plant in Amarillo.
- Cargill feedyard cattle go to the Cargill packing plant in Friona.

Adding to the complexity is that the feedyards can split shipments between different slaughterhouses. So not all of the cattle in a feedyard go to the same slaughterhouse. Because of these various transactional possibilities, the commodity flow modeling starts off with the simple assumption that all cattle from one feedyard will go to either the closest feedyard and slaughterhouse or to the slaughterhouse they are vertically integrated with. TCFA representatives indicated the slaughterhouse rarely turn away cattle from nearby feedyards due to capacity. The actual capacity of the plants will need to be estimated for estimating the number of truck trips.

For the commodity flow modeling, it will be assumed that all of the cattle in Texas feedyards will be shipped to one of those five slaughterhouses. The model also assumes no cattle are imported from outside Texas to the slaughterhouses (per conversations with cattle industry representatives that the vast majority of cattle processed are from Texas). When this project examines commodity flow irregularities, such as seasonal movement or climate impacts, consideration can be given to movement of cattle into the state to slaughterhouses.

5.1.4 Commodity Flow Estimation

Cattle Ranch to Auction House, Order-Buyer, Feedyard Movement

According to cattle industry association representatives, ranches usually send cattle to auction houses within 30 to 40 miles of the ranch, if the cattle go to auction. There is uncertainty of how many cattle go down each of the supply chain options. Whether they go through the auction house and/or order-buyer, the cattle will most likely end up at one of the feedyards.

Feedyard-to-Slaughterhouse Movement

To estimate the movement of cattle from the feedyard to the slaughterhouse, the number of cattle at each feedyard (assumed to be the capacity reported on the TCEQ CAFO permits) is summed for each county. If there is a feedyard vertically integrated with a specific slaughterhouse, the number of cattle from that feedyard is removed from the county total and set aside for the OD flow to the county with that particular slaughterhouse. For the remainder, the feedyard cattle are assumed to go to the slaughterhouses closest to the feedyard. In situations where there is a cluster of slaughterhouses, creating an obvious imbalance, a judgment is made on adjusting the percentage of cattle assigned to a slaughterhouse based on estimations of slaughterhouse capacity (found online).

Movement across State Boundaries

TAHC maintains data from permits issued for cattle brought into and out of Texas. Table 5.4 presents the cattle exports and Table 5.5 the imports for FY 2015. Not all cattle that enter or leave the state get permits, but this data provides a good approximation of the flow to each state. According to the data, Texas imports more cattle than it exports. For international flow, TAHC monitors the import of cattle from Mexico (by number of head and not by type of cattle). For calendar year 2013, 749 cattle were imported into Texas from Mexico; the figure for 2014 was 424 cattle, and for 2015, 3,106 cattle. Compared to the total number of cattle in Texas, the import movement across the Texas-Mexico border is quite small. The import of cattle from other states is quite significant though (over 2 million in FY 2015).

Table 5.4: Export of breeding cattle and cattle to other US states from TAHC permits (September 2014–August 2015)[8, 9]

BREEDING CATTLE - OUTSHIPMENT			
Alabama	403	Nebraska	941
Alaska		Nevada	390
Arizona	370	New Hampshire	
Arkansas	1179	New Jersey	15
California	123	New Mexico	6513
Colorado	316	New York	40
Connecticut		North Carolina	38
Delaware		North Dakota	13
Florida	1673	Ohio	286
Georgia	364	Oklahoma	3588
Guam		Oregon	17
Hawaii		Pennsylvania	3
Idaho	7	Puerto Rico	
Illinois	32	Rhode Island	
Indiana	8	South Carolina	8
Iowa	307	South Dakota	83
Kansas	1570	Tennessee	303
Kentucky	132	Utah	70
Louisiana	1547	Vermont	
Maine		Virginia	11
Maryland		Virgin Islands	
Massachusetts		Washington	4
Michigan	5	Washington, D.C.	
Minnesota	18	West Virginia	
Mississippi	452	Wisconsin	11
Missouri	906	Wyoming	60
Montana	47		
Total: 21,853			

CATTLE - OUTSHIPMENT			
Alabama	191	Nebraska	42059
Alaska		Nevada	30
Arizona	2411	New Hampshire	
Arkansas	946	New Jersey	
California	6603	New Mexico	12243
Colorado	20843	New York	4
Connecticut		North Carolina	
Delaware		North Dakota	
Florida	371	Ohio	
Georgia	54	Oklahoma	41918
Guam		Oregon	
Hawaii		Pennsylvania	
Idaho	10	Puerto Rico	
Illinois	602	Rhode Island	
Indiana		South Carolina	
Iowa	4155	South Dakota	327
Kansas	79833	Tennessee	165
Kentucky		Utah	50
Louisiana		Vermont	
Maine		Virginia	
Maryland		Virgin Islands	
Massachusetts		Washington	
Michigan		Washington, D.C.	
Minnesota	1669	West Virginia	
Mississippi	148	Wisconsin	1201
Missouri	909	Wyoming	790
Montana	33		
Total: 217,565			

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[8] Receipts of all cattle by State of Destination as tabulated from certificates of veterinary inspections filed

[9] An empty cell means no certificate of veterinary inspection forms were received from that state.

Table 5.5: Import of beef cattle from other US States from TAHC permits (September 2014–August 2015)

BEEF CATTLE - INSHIPMENT			
Alabama	63609	Nebraska	25987
Alaska		Nevada	2830
Arizona	444040	New Hampshire	
Arkansas	90089	New Jersey	
California	120004	New Mexico	103765
Colorado	32378	New York	12
Connecticut		North Carolina	1560
Delaware		North Dakota	8399
Florida	306954	Ohio	4755
Georgia	31672	Oklahoma	417374
Guam		Oregon	5216
Hawaii	5799	Pennsylvania	1116
Idaho	66950	Puerto Rico	
Illinois	2340	Rhode Island	
Indiana	5716	South Carolina	19743
Iowa	1365	South Dakota	28316
Kansas	70869	Tennessee	5768
Kentucky	46386	Utah	4101
Louisiana	47480	Vermont	
Maine	1	Virginia	405
Maryland	5	Virgin Islands	
Massachusetts	1	Washington	754
Michigan	2691	Washington, D.C.	
Minnesota	7030	West Virginia	74
Mississippi	143181	Wisconsin	2528
Missouri	41348	Wyoming	13983
Montana	39024		
Total: 2,215,618			

5.1.5 Transportation

Truck Type

For cattle movement to auction houses or order-buyer facilities from ranches, smaller truck and trailer combinations (Figure 5.8) are used for cattle transport.

Figure 5.8: Trailer Truck Combo for Short Distance Haul of Cattle (Renville Sales, 2016)

For cattle movement to feedyards and slaughterhouses, a common truck option is the five-axle truck with a specialized livestock trailer for hauling cattle. Feeder cattle must be moved only by truck due to regulations governing the transport of live animals. Figure 5.9 shows a five-axle livestock tractor trailer with a split tandem axle. Figure 5.10 shows a five-axle livestock tractor trailer with a standard tandem axle and reduced trailer height.

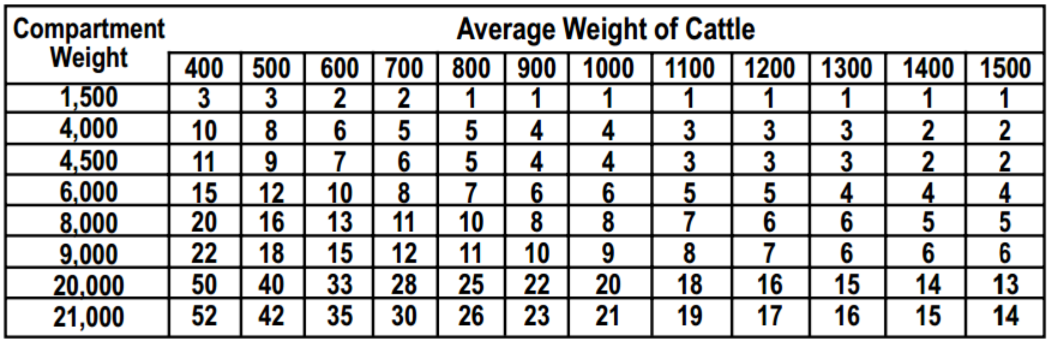
Figure 5.9: Livestock Trailer with Split Tandem Axle

Figure 5.10: Livestock Trailer with Standard Tandem Axle and Reduced Trailer Height

Truck Capacity

According to *Master Cattle Transporter Guide* (National Cattlemen's Beef Association, 2016), a 48-ft livestock trailer can carry about 50,000 lbs of cattle and a 53-ft trailer can carry about 55,000 lbs of cattle. The number of cattle that can be carried by a truck will vary depending on their weight. According to communication with the Texas Cattle Feeders Association, the average finished steer usually weighs about 1,400 lbs. Therefore, based on the values shown in Table 5.6, Figure 5.11, and Figure 5.12, the 48-ft trailer can carry 34 cattle and the 53-ft trailer can carry 38 cattle.

Table 5.6: Number of cattle that can be loaded based on cattle weight and trailer compartment weight (*Master Cattle Transporter Guide*)



Compartment Weight	Average Weight of Cattle											
	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
1,500	3	3	2	2	1	1	1	1	1	1	1	1
4,000	10	8	6	5	5	4	4	3	3	3	2	2
4,500	11	9	7	6	5	4	4	3	3	3	2	2
6,000	15	12	10	8	7	6	6	5	5	4	4	4
8,000	20	16	13	11	10	8	8	7	6	6	5	5
9,000	22	18	15	12	11	10	9	8	7	6	6	6
20,000	50	40	33	28	25	22	20	18	16	15	14	13
21,000	52	42	35	30	26	23	21	19	17	16	15	14

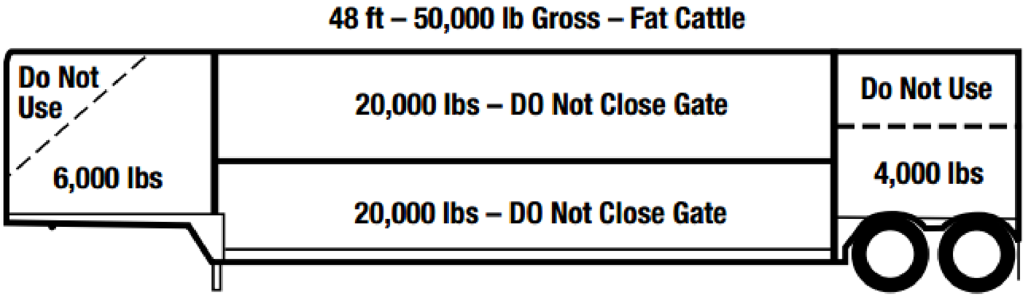


Figure 5.11: Compartment Weight of 48-ft Livestock Trailer When Carrying Fat Cattle (Master Cattle Transporter Guide)

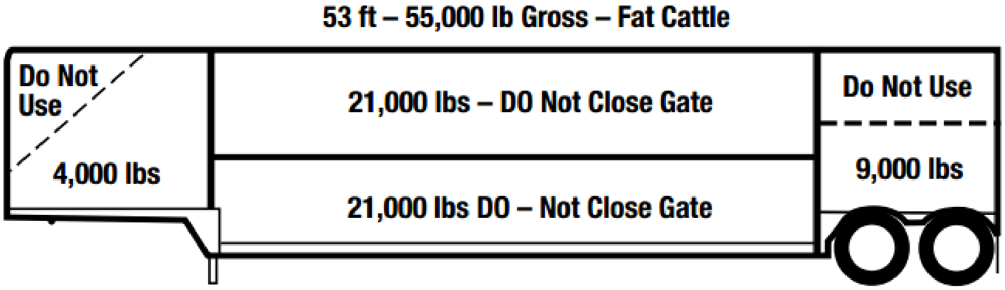


Figure 5.12: Compartment Weight of 53-ft Livestock Trailer When Carrying Fat Cattle (Master Cattle Transporter Guide)

Converting Tonnage to Equivalent Trucks

Assuming on average each livestock truck transports 36 cattle, the number of loaded livestock trucks required to move the cattle between counties can be calculated based on the flow matrix developed in section 5.1.4.

Estimating Empty Trucks

Because transporting cattle requires the exclusive use of livestock trucks, after delivering cattle at the slaughterhouses, these trucks usually return empty without carrying any load. Therefore, it is assumed that the same number of empty trucks will be travelling back from slaughterhouses to feedyards.

Following the steps described above, the research team estimated the county-to-county matrix of the number of five-axle livestock trucks used to transport cattle; the results are included in Appendix 1 of this report.

5.1.6 Network Analysis

The truck trips for the transport of cattle from feedyards to slaughterhouses are represented in Figure 5.13. Cattle truck trips are most heavily concentrated in the Panhandle. US 87 north of Amarillo has the most cattle truck trips, estimated at more than 36,000 per year. US 287 north of Dumas, IH 27 between Amarillo and Canyon, and US 60 and US 84 east of Farwell also carry high numbers of cattle trucks.

The value of cattle used in this study is $105 per 100 lbs, which was estimated using the November 2016 average price for slaughter cattle from *The Cattle Range* weekly market summary (The Cattle Range, 2016). Based on this value, a 1400-lb cow is worth $1,470 and a truck carrying thirty-six cattle is worth $52,920.

Figure 5.14 displays the estimated value (in thousands) of cattle movements on the Texas primary and secondary freight networks. The road section most heavily used by cattle trucks (US 87 north of Amarillo) carries more than $1.8 billion of cattle annually.

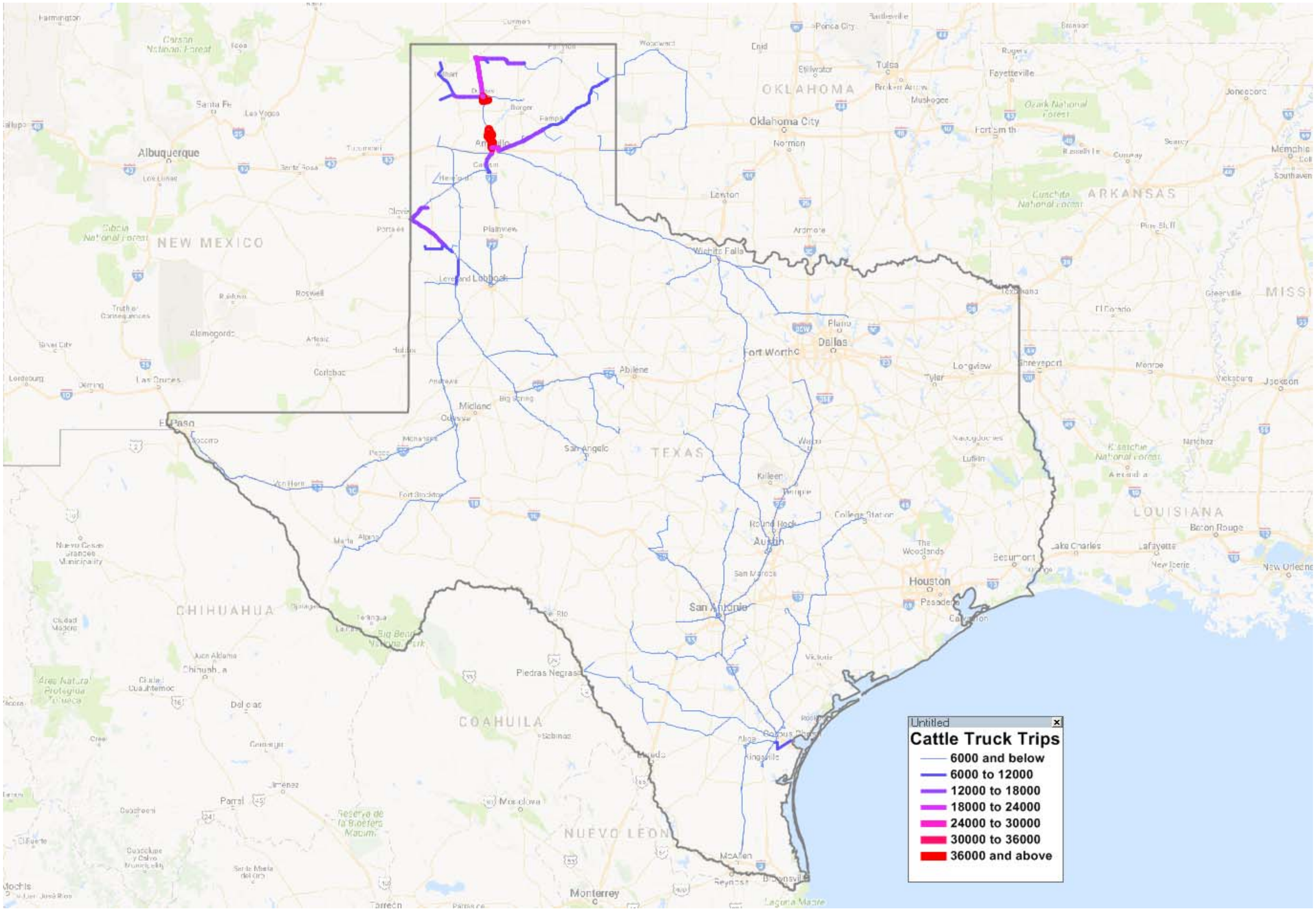


Figure 5.13: Cattle Truck Trips

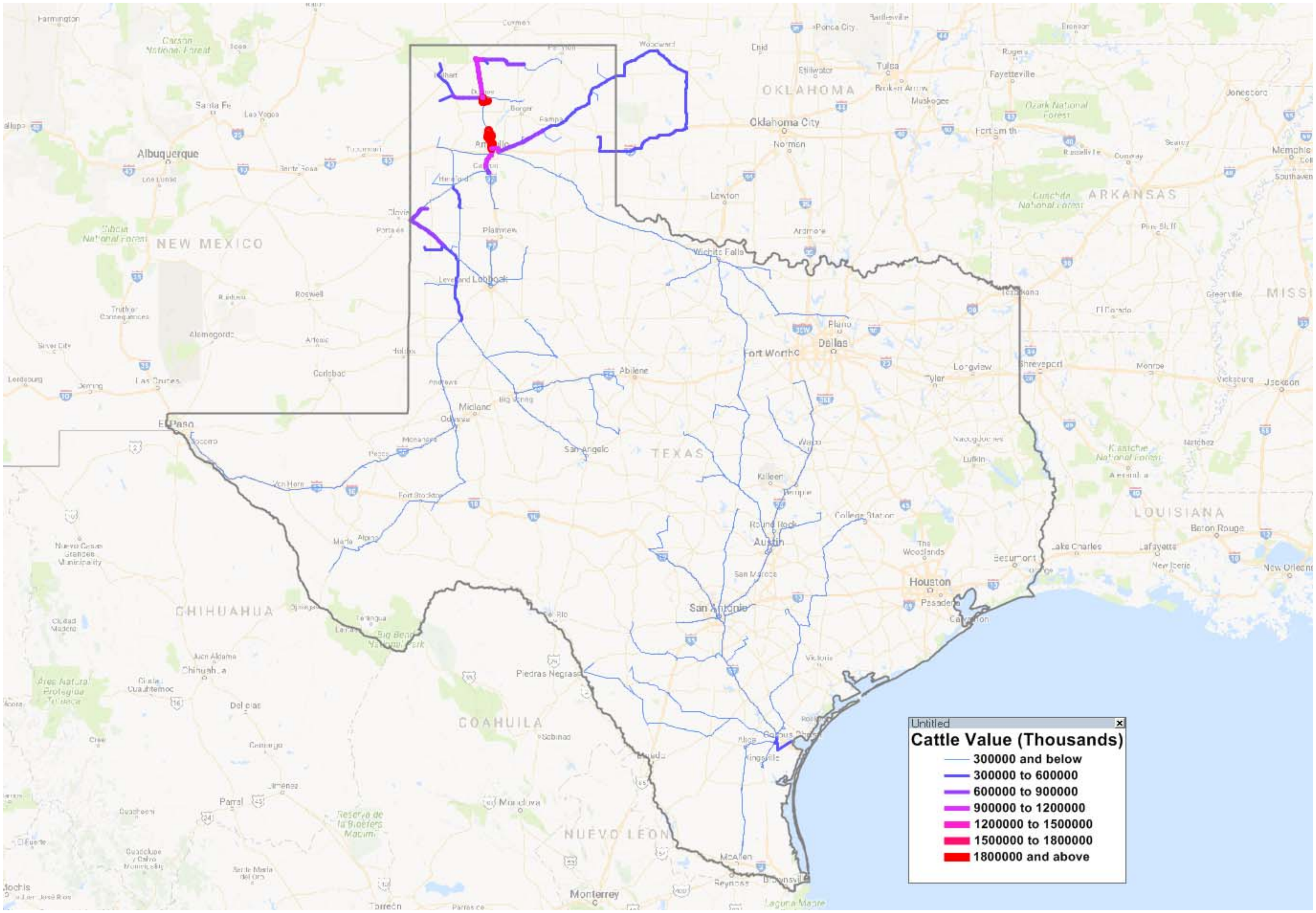


Figure 5.14: Cattle Value

5.1.7 Compare with Transearch data

As shown in Table 4.1, the closest commodity category to cattle in the Transearch database is livestock (STCC 01 41). The research team processed the livestock data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.15. It can be seen that the Transearch livestock truck flows focus in the panhandle area. This matches the cattle flows assignment results fairly well even though the STCC code 01 41 includes all livestock trips. This is likely because cattle is such an important livestock commodity to Texas, and constitutes the majority of livestock flows.

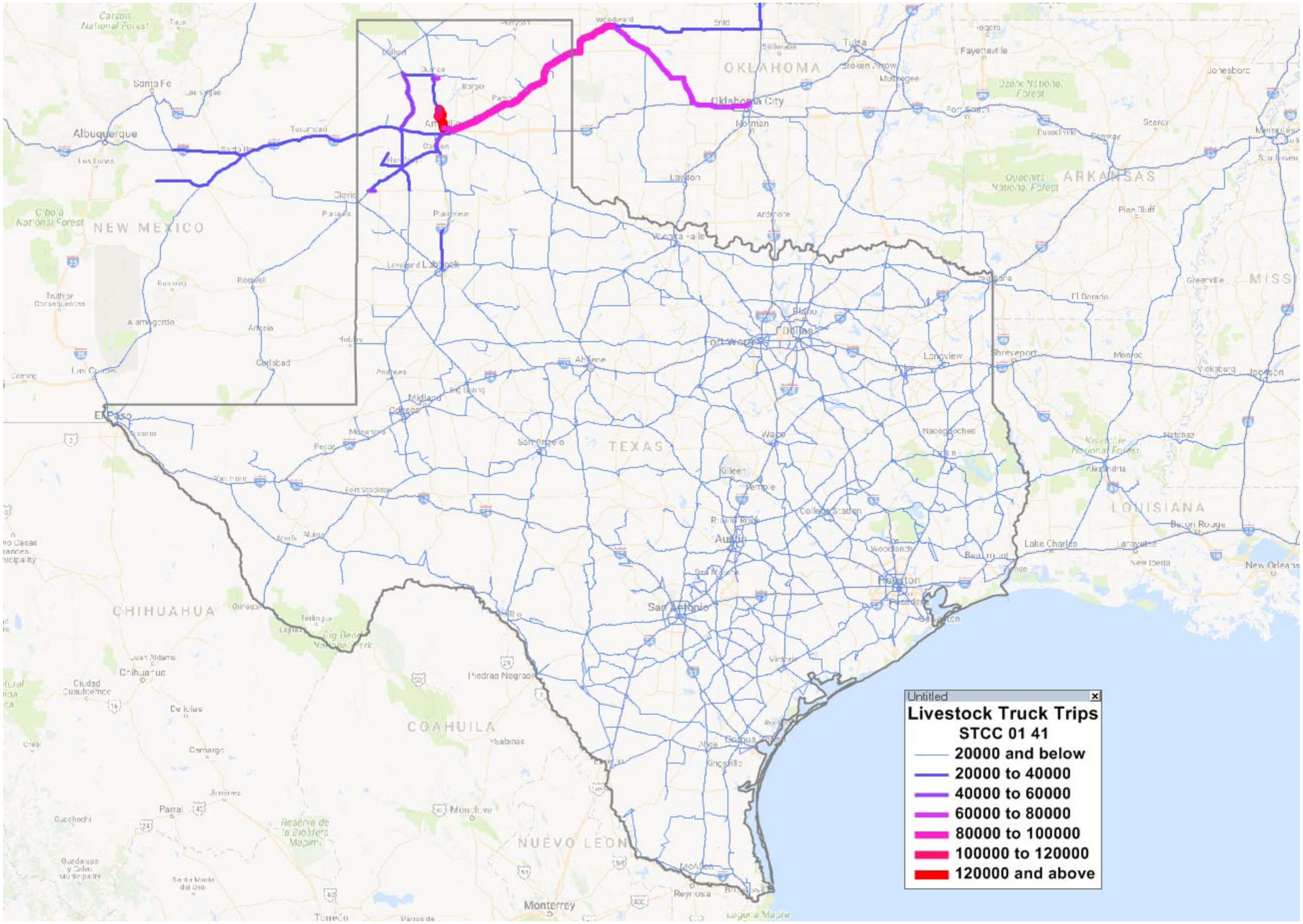


Figure 5.15: Transearch Livestock Truck Trips

5.1.8 Seasonal Variation

As described in Section 5.1.2, the supply chain of cattle begins at a ranch and passes several intermediate facilities (auction sites and order buyers' yards) and proceeds to feedyards. Based on the need for meat products, the cattle are then transported to the slaughterhouse. Generally, most big ranches in Texas send cattle directly to feedyards without passing through an auction site or order buyers' yard. Therefore, the transport of cattle can be generalized as having two paths: from ranch to feedyard and from feedyard to slaughterhouse. The data of cattle slaughtered and cattle on feed are respectively used to identify the seasonal variation of these two paths of cattle flow.

From Ranch to Feedyard

The research team assumed that the cattle flow from ranch to feedyard has the same seasonal variation as cattle inventory in the feedyard. The data for Texas cattle inventory was collected from the USDA's monthly reports of cattle on feed (USDA, 2017). The number of cattle on feedyards in both 2015 and 2016 were recorded and used to calculate the proportion of each month. The Texas inventory of cattle in feedyards is in the range of 242 and 261 million heads. The USDA's monthly report also provides the run sequence plot of Texas monthly cattle on feed inventory for both 2015 and 2016 as shown in Figure 5.16. Although the general patterns of variation for both years are not completely the same, they have a similar trend of increment and decrement for most months, especially in summer and winter. The maximum inventory happened in May 2016, which accounts for 8.75 percent; minimum inventory happened in January 2016, which accounts for up to 8.11 percent (see Figure 5.17). In 2016, the trend shows that the inventory of cattle gradually increases from January, reaching the highest point in June and then gradually decreasing until the end of the year. In 2015, inventory of cattle on feedyards gradually decreases from January until May, with two obvious increases happening in June and November. The variation in 2015 is relatively smoother than 2016. It must be mentioned that June and November are the months of distinct increases in inventories for both years.

An average monthly value of cattle on feedyards is calculated from 2015 and 2016 data. The chi-square is calculated as X^2=21.925. Since this value is larger than the critical ($X^2 = 21.925 > X_t^2 = 5.58$), the null hypothesis is rejected. In other words, based on the data from 2015 and 2016, the transportation of cattle from ranch to feedyard has seasonal variation. More trucks carrying cattle from ranch to feedyards are expected to be seen in June and November.

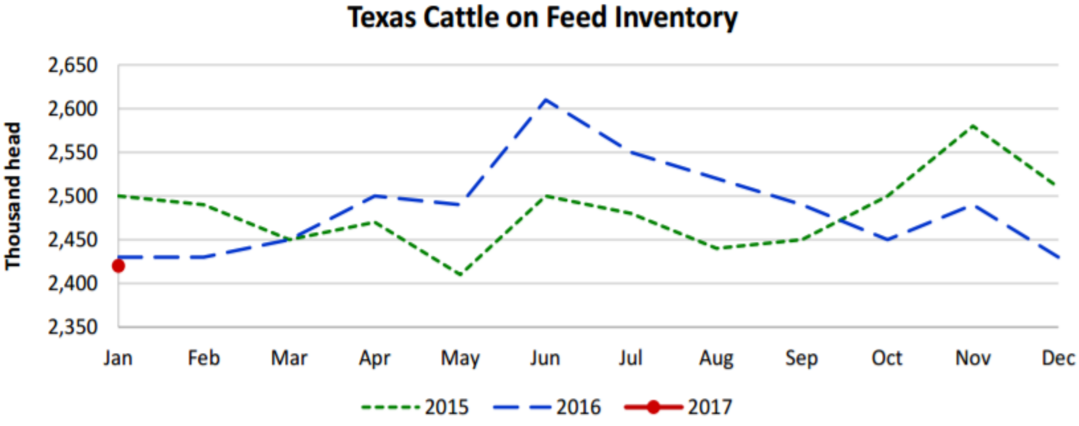


Figure 5.16: Run Sequence Plot of Cattle on Feedyards in Texas

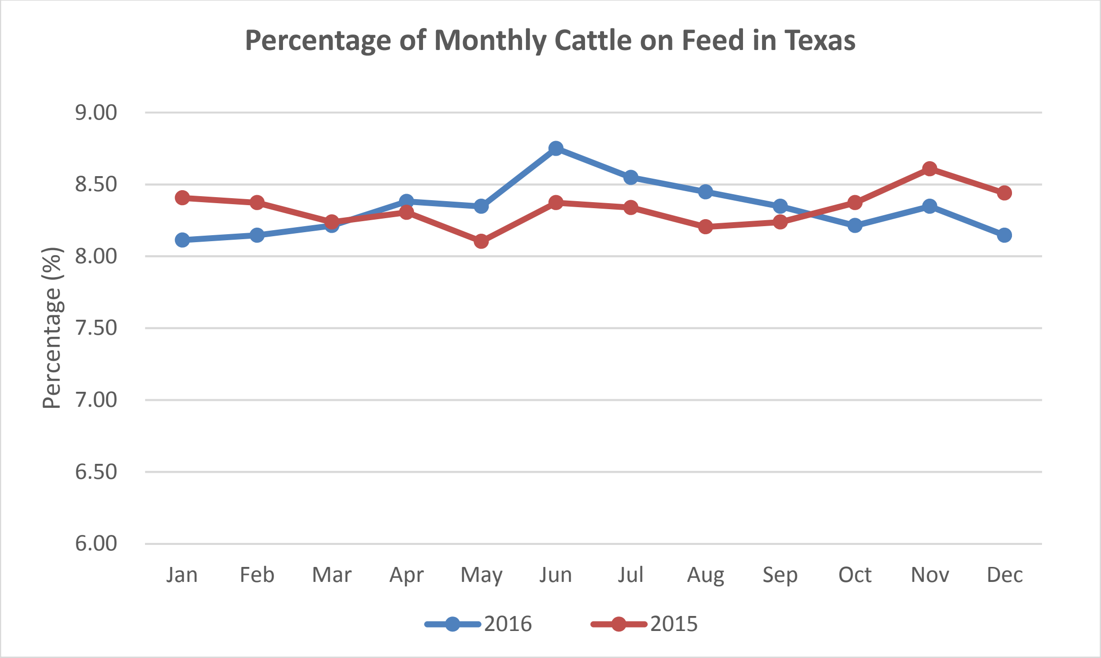


Figure 5.17: Run Sequence Plot of Monthly Percentage Cattle on Feedyards in Texas

From Feedyard to Slaughterhouse

The variation of cattle flow from feedyards to slaughterhouses is assumed to have the same seasonal change as the number of cattle slaughtered. The research team collected data from commercial cattle slaughtered in Texas for each month of 2015 and 2016 from USDA's reports. Based on the collected data, Texas's total number of slaughtered cattle is 5.44 million in 2016 and 5.06 million in 2015. Figure 5.18 shows the monthly change of number of slaughtered cattle for both years. As the graph shows, the general variation patterns of 2015 and 2016 are similar despite a slight difference during the winter. For both years, there is an evident decline in February and then a slight fluctuation until May. After that, a spike occurred in June. In winter, the number of slaughtered cattle tended to decrease.

The highest number of cattle slaughtered, 488,000, happened in June 2016; the lowest number of cattle slaughtered, 381,000, occurred in February 2015. The range (about 100,000 head) is quite large. Comparing to the cattle flow from ranch to feedyard, the movement from feedyard to slaughterhouse have more obvious seasonal variation.

As in the last section, the monthly value is averaged from both years. The chi-square value then turned out to be X^2=11.88, which is much larger than critical value ($X^2 = 11.88 > X_t^2 = 5.58$). Thus, it is reasonable to conclude, based on the data, that the movement of trucks carrying cattle from feedyard to slaughterhouse has obvious seasonal variation.

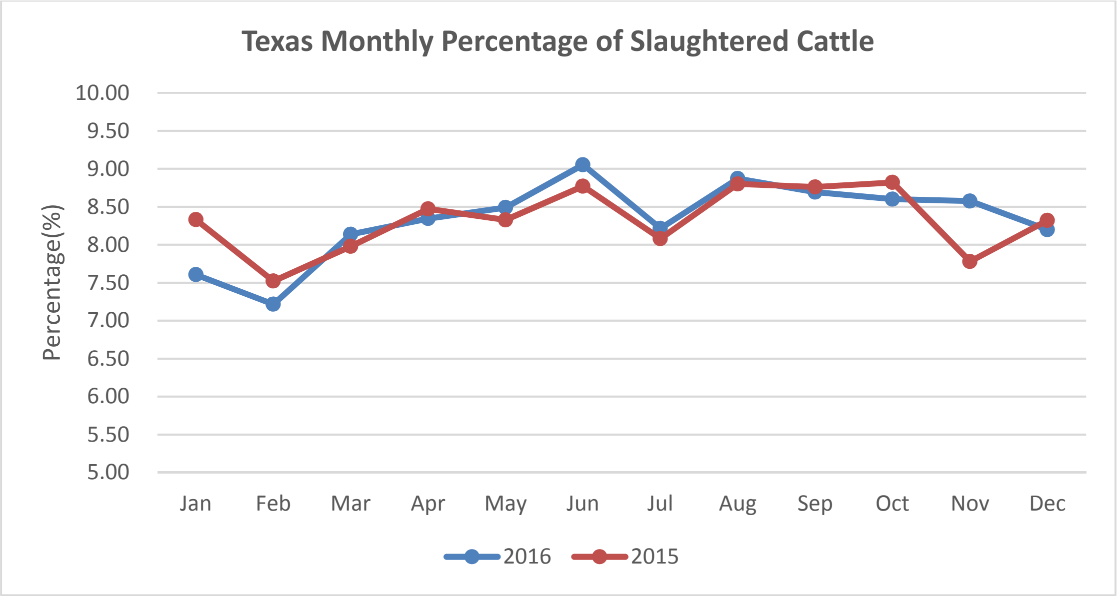


Figure 5.18: Run Sequence Plot of Monthly Percentage of Slaughtered Cattle in Texas

5.1.9 Daily Truck Trip Assignment

In the previous section, June is estimated as the month with highest number of cattle trucks moving between feedyards and slaughterhouses. The daily cattle truck trips in June is calculated using the method described in Section 4.5.3 and the results are as follows:

- Annual truck trips: 120,112
- Peak month: June
- Peak month percentage: 9%
- Peak month daily truck trips: 362

Figure 5.19 shows the distribution of those trucks on the network. The flow pattern is quite similar to the one shown in Figure 5.13, which did not consider the impact of congestion. This is mainly because cattle truck trips are moved on those roadways in the Panhandle area that are not heavily congested. US 87 north of Amarillo carries the highest number of truck trips—more than 100 per day.

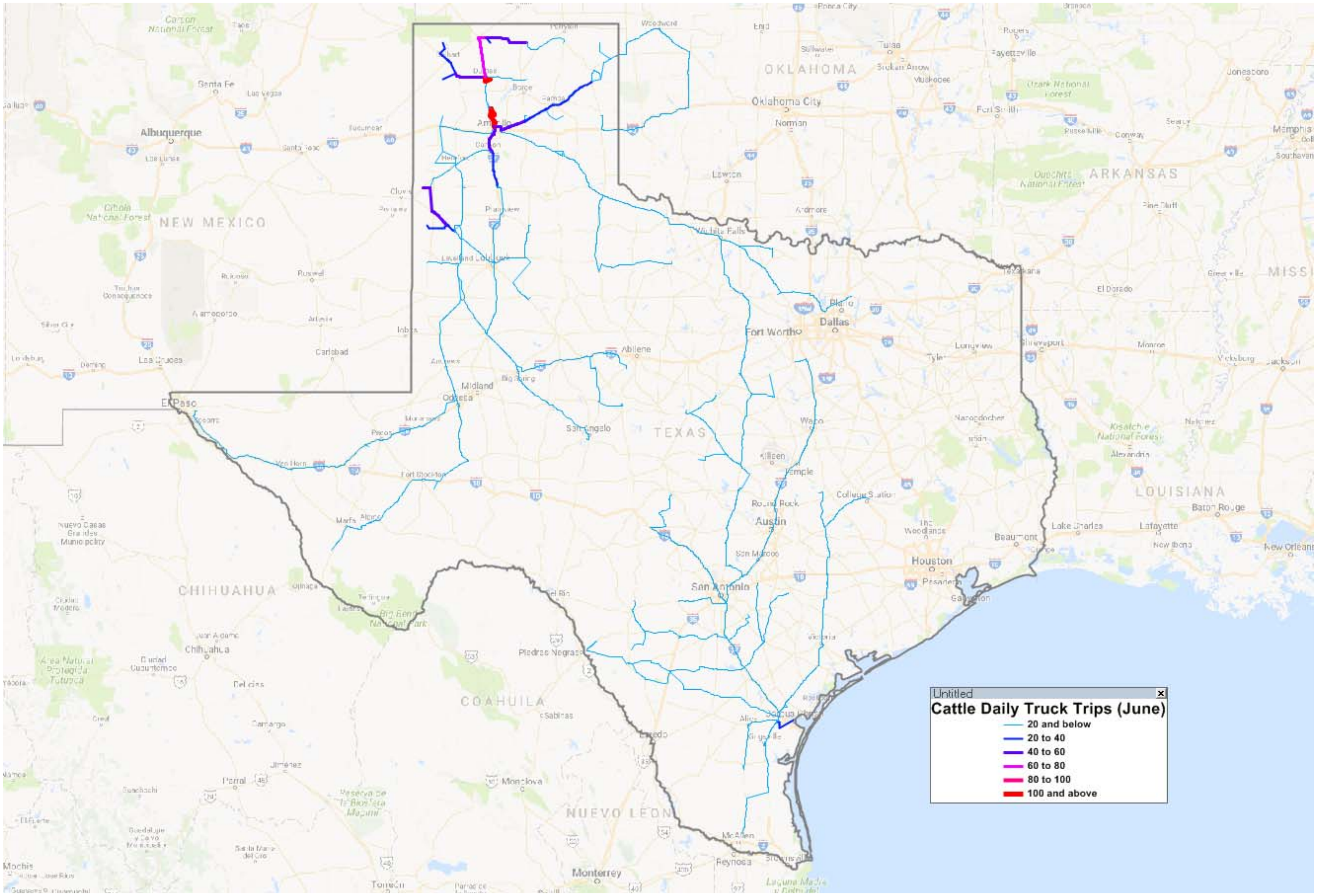


Figure 5.19: Cattle Daily Truck Trips in June

5.1.10 Summary

The cattle industry in Texas is not only the top agricultural commodity for the state (and because of the demand for grain, boosts the sales of grain and corn for production), but also a very truck-intensive industry. Cattle are shipped by truck in every link of each of the possible supply chains. The emphasis for this project was on the flow of cattle from the feedyards to slaughterhouses because of the data availability. The flows for other links of the supply chain were a little more difficult to estimate because of the uncertainty of how many cattle enter each of the supply chain options, but the data available gives an indication of the general movement of cattle within the state (generally central-east to the Panhandle).

The network analysis results (with or without considering the impact of congestion) confirms that trend, showing that cattle truck trips are concentrated in the Panhandle area. US 87 north of Amarillo has the most cattle truck trips, carrying cattle worth more than $1.8 billion annually. Cattle is a commodity with significant seasonal variations. The month with the most movement of cattle trucks between ranch and feedyards and between feedyards and slaughterhouses is June. We estimated that more than 100 cattle trucks per day move on US 87 north or Amarillo during June.

5.2 Grain Sorghum & Corn

5.2.1 Background

The corn and grain sorghum commodities are an integral part of the cattle supply chain, a commodity with a large production and economic significance in Texas. Although Texas produces nearly 200 million bushels of sorghum and 265 million bushels of corn per year (2015), the state has a grain deficit, meaning that most of the grain (both sorghum and corn) produced within the state will remain within the state for its final use. Additionally, a large proportion of the total sorghum and corn produced in Texas is utilized at cattle feedyards. The Panhandle is home to many sorghum and corn farms and cattle feedyards, meaning that the flow of these grains to cattle feedyards is localized.

5.2.2 Supply Chain

The modeling focus will be the flow of grain sorghum and corn from the farms to grain elevators and then from grain elevators to the cattle feedyards, as illustrated in Figure 5.20. Farmers look to deposit their grain at the nearest elevators, meaning that the flow of sorghum and corn to these elevators will remain local, mostly within the county. From the elevators, only the portion of grain transported to the cattle feedyards by truck will be considered. This portion varies depending on the location within the state. Elevators in north Texas and the Panhandle transport much more grain to cattle feedyards than elevators on the Gulf Coast.

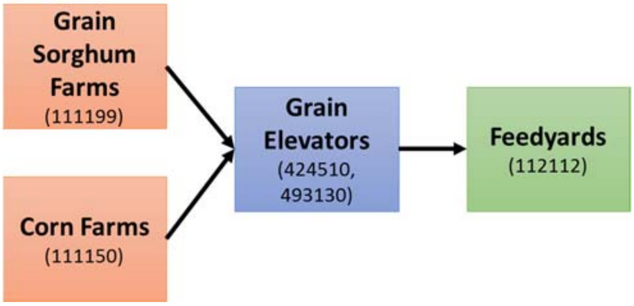


Figure 5.20: Grain Sorghum and Corn Supply Chain

Grain imports into the state by rail are added to this modeling effort once the grain is deposited at the rail elevator. Nearly all of the grain imports into Texas for use as feed are transported by railroad.

5.2.3 Datasets

The following free public data sources were used in this modeling effort:

- USDA's NASS Southern Plains Regional Field Office County Production Estimates for 2015 – Data included acreage planted, acreage harvested, yield per harvested acre and production (in bushels) for both sorghum and corn, broken down by county (United States Department of Agriculture, 2016). Figures 5.21 and 5.22 from the USDA depict the amount of grain sorghum and corn produced in each county.

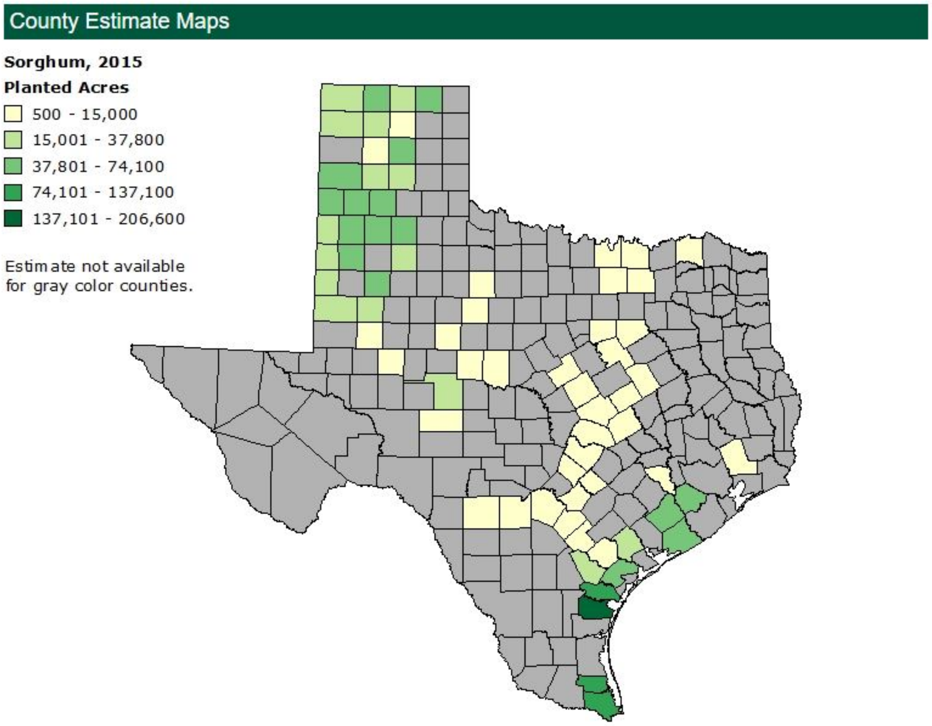


Figure 5.21: County Production Estimates for Sorghum, 2015

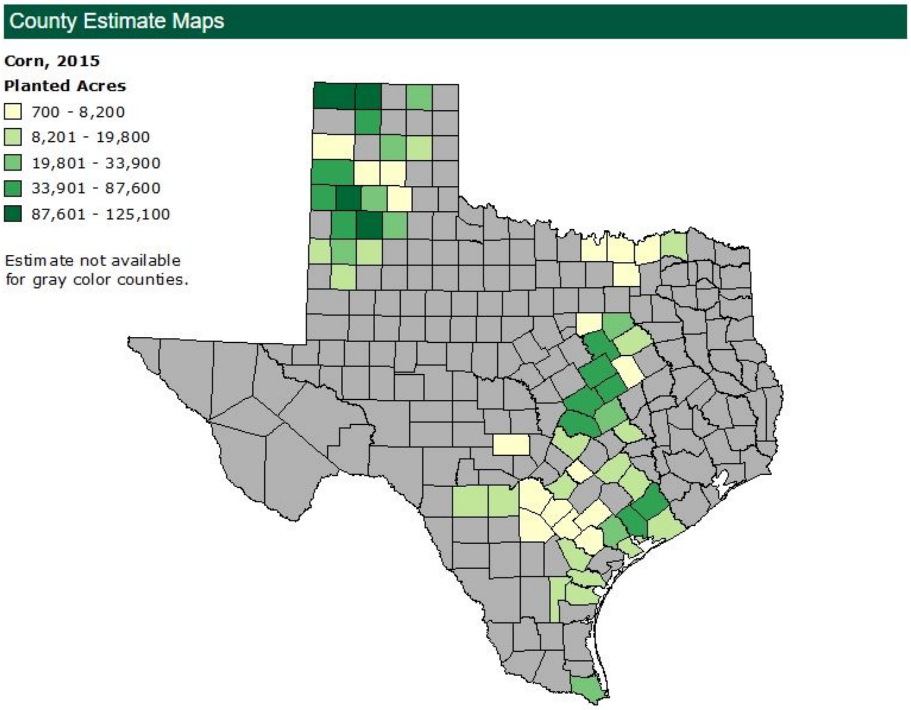


Figure 5.22: County Production Estimates for Corn, 2015

- TWC Data – Grain elevators, sorted by NAICS code, were included in this modeling effort. Figure 5.23 depicts the grain elevator locations in the state.

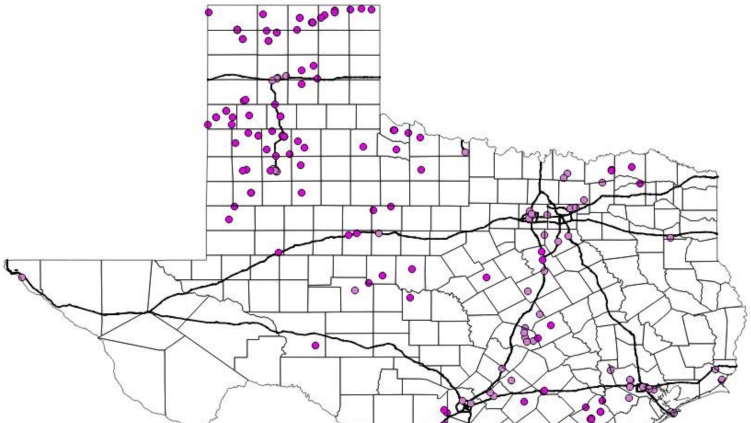


Figure 5.23: TWC Data Grain Elevator Locations

- BNSF Elevator Directory and Map – Our model included major elevators used for railroad shipments imported into Texas (BNSF Railway, 2016). Figure 5.24 depicts the grain elevators identified by the BNSF data.

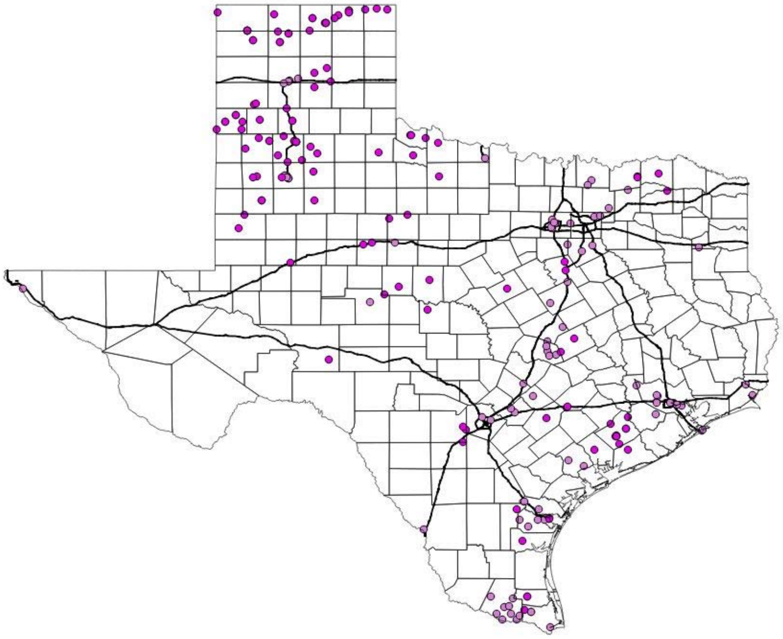


Figure 5.24: BNSF Data Grain Elevator Locations

- USDA Census of Agriculture 2012 – The hogs and pigs inventory, as well as change in inventory data and maps, are included in the modeling effort (United States Department of Agriculture NASS, 2012).
- USDA Meat Animals Production, Disposition, and Income: 2014 Summary – The total number of hogs marketed in Texas is included in this modeling effort to determine the amount of grain traveling to hog farms (United States Department of Agriculture NASS, 2015).
- TCEQ Permit Data – The permitted cattle feedyards in Texas are included in this modeling effort (see cattle section for more about cattle feedyards and map of their locations). Figure 5.25 shows the feedyard locations in relation to the boundaries of MPOs.

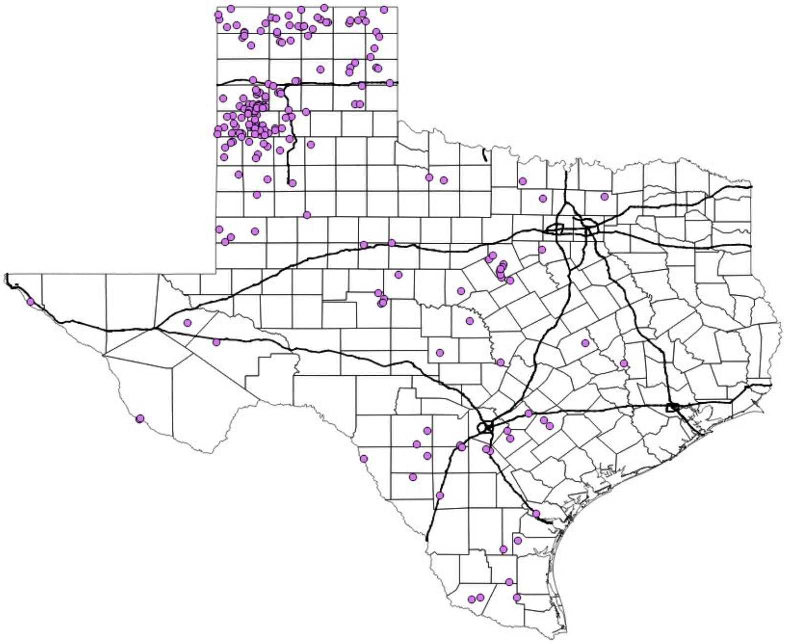


Figure 5.25: TCEQ Data Cattle Feedyard Locations

None of these reference sources used commodity codes other than the NAICS system.

5.2.4 Commodity Flow Estimation

County Productions to Grain Elevators

The total productions of sorghum and corn by county were taken directly from the USDA NASS county production estimates and aggregated together after allocation to grain elevators. This aggregation is possible because bushels of sorghum and corn both weigh 56 pounds (University of North Carolina at Chapel Hill, 2001).

From here, the total number of elevators accepting this grain needed to be determined from the TWC data. In order to account for the elevators identified by the BNSF data as accepting grain from railroad shipments, the elevators identified by both datasets were removed from the TWC list. The assumption was made that all grain produced in Texas was not shipped to any of the elevators identified by the BNSF dataset. This assumption can be made within this model because the grain will travel to its nearest elevator for deposit, assuming there is room at that elevator. Therefore, a large proportion of the grain will only travel within the county where it was produced for the first step of the supply chain model. Additionally, the BNSF-identified elevators will most likely be filled with grain imported into Texas via rail.

Once the number of elevators in each county was determined using the abridged TWC data, an estimate of the size of each elevator was made using the number of employees at that elevator. For each 10 employees (or part thereof) at an elevator, a capacity of 1 million bushels was assigned. Again, this assumption can be made because once aggregated to a county level, especially in the Panhandle, an exact capacity at each elevator is not required.

Once the productions at each county and the attractions (elevator capacity) for each county were determined, an algorithm was run to allocate the grain productions for each county to its closest elevator. The algorithm allocated county attractions to their closest county elevators until those county elevators reached capacity. Once the capacity for elevators in a county was reached, the next farthest county from one county's elevators (that should have drawn its attractions from those elevators) would instead draw from its second closest county elevators.

In reality during the algorithm run, most of the sorghum and corn was allocated to its own county's elevators. If those elevators could not handle the capacity, or that county did not have any elevators, the grain would instead be allocated to the next closest county with additional capacity. This algorithm was generated in MATLAB and the output from this algorithm has been included in the Appendix 1 of this report.

Determining Grain Flow from Elevators to Feedyards

Once the amount of grain flowing to each county's elevators was determined, the amount of grain continuing on to Texas feedyards needed to be estimated. The *Texas Grain Transportation Study* performed a survey of county elevators in Texas to determine the amount of grain transported to Texas feedyards (Stephen Fuller, 2001). The study broke down the survey based on the regions within Texas shown in Figure 5.26.

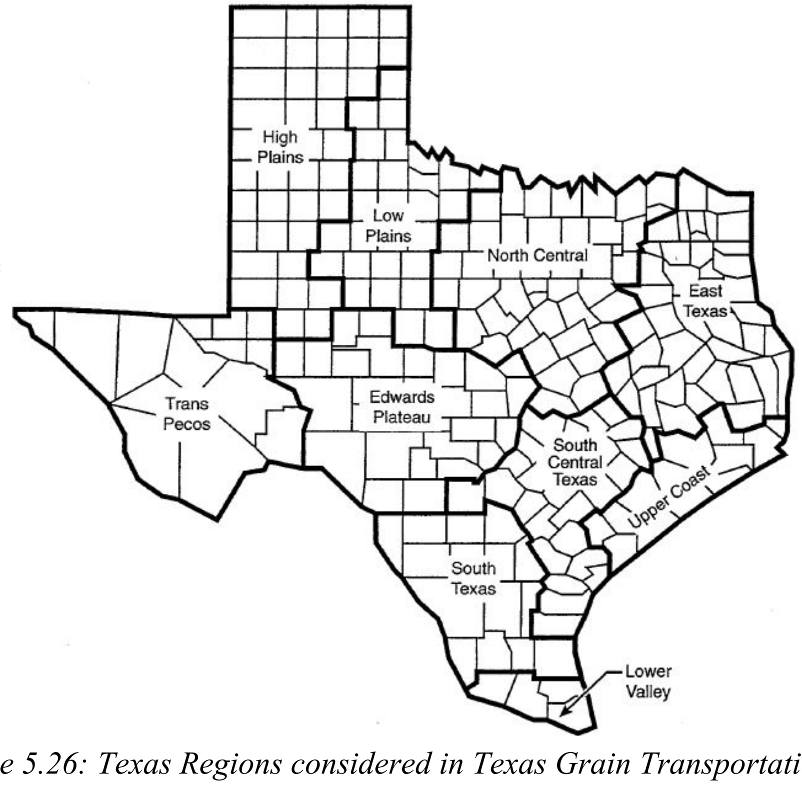


Figure 5.26: Texas Regions considered in Texas Grain Transportation Study

As expected, a large proportion of the grain at county elevators in the High Plains and Low Plains regions in north Texas proceeded to Texas feedyards, whereas a very small proportion in the Upper Coast, South Central Texas, and the Lower Valley proceeded to Texas feedyards. It was determined where each county in Texas was classified based on the above map. For each county, the amount of sorghum and corn was separately multiplied by their proportions proceeding from elevators to feedyards by truck. From this point forward, the amount of sorghum and corn is aggregated for further modeling and analysis.

The capacity at each BNSF-identified elevator was determined using a spreadsheet downloaded from the BNSF website (BNSF Railway, 2016). For elevators where the capacity was not given, a regression analysis was estimated based on the track capacity (number of railroad cars that could fit at each terminal) and the number of employees at each terminal (if the elevator was also included in the TWC data). The regression analysis produced very poor and uninterpretable results. R^2 values were 0.17 for the regression relating track capacity to elevator capacity and 0.08 for the regression relating both track capacity and number of employees to elevator capacity.

Therefore, since a regression analysis could not be used, estimates for elevator capacity were determined by hand. Factors that were considered included track capacity, number of employees, the railroad serving that elevator, any elevators of similar size and any elevators of the same company. These elevators were assigned to counties by overlaying a GIS shapefile of Texas counties onto the shapefile of BNSF-identified grain elevators. Then the total capacities for all elevators within a county were aggregated.

The amount of grain flowing from each of the BNSF-identified elevators to hog farms needs to be considered. In order to estimate the amount of grain diverted from these elevators for this purpose, the total sale of hogs in Texas was identified using USDA data (United States Department of Agriculture NASS, 2015). The total amount of grain consumed (in bushels) was calculated based on proportions of grain consumption per hog identified in the *Texas Grain Transportation Study*. The total amount diverted is 31.2 million bushels.

In order to estimate from which elevators this grain was diverted, an estimate of the locations of hog farms was determined using the *Texas Grain Transportation Study* and USDA NASS maps (United States Department of Agriculture NASS, 2012). It was estimated that 80% of the total hog farms in Texas are situated in the High Plains, 15% in the Low Plains, and 5% in East Texas, based on the regions in Figure 5.26. The total amount of grain diverted from each elevator was separated by region and based on the capacity of the elevator.

Grain Elevators to Cattle Feedyards

The cattle feedyards in Texas were identified by TCEQ permit data for CAFOs. The data also included the size of each feedyard (in head of cattle). Based on the total amount of grain identified in the previous step as flowing to cattle feedyards, an estimate of the amount of grain flowing to each feedyard was determined. The feedyards were assigned to counties by overlaying a GIS shapefile of Texas counties onto the shapefile of TCEQ-identified feedyards. The total consumption of grain was aggregated to a county level for further analysis.

A gravity model was run to allocate the productions for each county (i.e., the amount of grain at county elevators transported by truck to cattle feedyards) to attractions for each county (the amount of grain consumed at each county's cattle feedyards). Road distance between each county was used as a friction factor in the model. The model was run using all 254 counties in Texas, but a majority of the productions and attractions were 0. In fact, 80 counties contained grain elevators and 69 counties contained feedyards.

5.2.5 Transportation

Truck Type

Grain trucks are used to transport grain sorghum and corn from farms to elevators and then from elevators to cattle feedyards. Five-axle tractors with grain hauler trailers (Figure 5.27) are most often used for grain transportation, representing upwards of 75–80% of total grain movements from farms to elevators and nearly all of grain movements from elevators to cattle feedyards. Two- or three-axle straight trucks (Figure 5.28) are used for the remaining transport from farms to elevators. The remaining smaller two- or three-axle straight trucks are being phased out in favor of larger tractor-trailer combination vehicles that can carry more weight for a longer distance, requiring fewer truck trips (Richardson, 2016).

Figure 5.27: Five-axle Tractor with Grain Hauler Trailer (FFA New Horizons, 2016)

Figure 5.28: Three-axle Grain Truck (Purple Wave Auction, 2016)

Truck Capacity

Due to the weight of both corn and grain sorghum at 56 pounds per bushel, trucks transporting these products are usually limited by a weight restriction rather than volume (Rowlett, 2001). Grain trailers can haul upwards of 1,100 bushels, with straight grain trucks hauling anywhere from 300 to 700 bushels depending on the size and weight restriction of the vehicle (Jet Trailers Co., 2016). However, given a typical weight of 15,000 pounds for a truck tractor and 10,000 lbs for a grain trailer, a truck operating at the agricultural exemption weight of 84,000 lbs is limited to approximately 1,050 bushels of corn or grain sorghum.

Converting Bushels to Equivalent Trucks

Corn and grain sorghum can be transported from farms to elevators using any type of truck available to the farmer. Many farmers previously used straight grain trucks, but most are transitioning to the larger five-axle tractor-grain trailer combination vehicle. These larger trucks can carry larger amounts of grain over longer distances. It has been estimated that only 20% of grain transport from farms to elevators is still done using straight grain trucks. The remaining 80% of transport uses larger tractor-trailers.

Due to the many different types of grain trucks still in use today, a complete breakdown of the grain trucks and their bushel capacities could not be estimated. A typical three-axle straight grain truck (Figure 5.28) has been selected for this analysis. The gross vehicle weight restriction (GVWR) for this vehicle is 54,000 pounds, or 56,700 pounds with the 5% agricultural exemption allowed in Texas. Given an empty weight of 20,000 to 25,000 pounds, this truck can transport approximately 600 bushels of corn or grain sorghum.

Furthermore, it is assumed that these trucks will be operated at full capacity since farmers wish to transport their crops to elevators as quickly as possible in the harvest season. Based on the estimated breakdown of trucks and their capacities, a typical truck transporting corn or grain sorghum from a farm to an elevator contains 960 bushels.

For transportation from elevators to cattle feedyards, larger tractor-trailers will be utilized (Richardson, 2016). Grain trucks are not often used from this transport as the product will travel longer distances. Since these trucks trips are not operating under the state's agricultural exemption, the truck is limited to carrying approximately 1,000 bushels of corn or grain sorghum. The number of truck trips is calculated from this estimated capacity of tractor-trailer grain haulers.

Estimating Empty Trucks

For the first part of the supply chain, transporting corn and grain sorghum from farms to elevators, it is assumed that trucks will return to the farms empty. Most of the trucks are owned by the farmers using them to transport the product.

Trucks transporting corn and grain sorghum from elevators to cattle feedyards may return to the elevators empty or may be used by the cattle feedyards for transportation of other materials. These trucks trips are not included in this matrix since it is anticipated that they do not contain corn or grain sorghum.

Following the steps described above, the county-to-county matrix of number of trucks used to transport corn and grain sorghum was estimated and the results are included in Appendix 1 of this report.

5.2.6 Network Analysis

The assignment procedure for grain sorghum and corn was broken down into separate stages for transport from farms to elevators and then from elevators to feedyards, to align with the OD and truck trip matrices developed in previous sections. The truck trips for the transport of grain sorghum from farms to elevators are represented in Figure 5.29 (Class 6), Figure 5.30 (Class 9), and Figure 5.31 (Total). The truck trips for the transport of corn from farms to elevators are represented in Figure 5.32 (Class 6), Figure 5.33 (Class 9), and Figure 5.34 (Total). The truck trips for both grain sorghum and corn transport from elevators to feedyards are represented in Figure 5.35.

As anticipated, most of the farm-to-elevator truck trips for both grain sorghum and corn are very short distances. Flow was allocated from farms to the nearest elevators that possessed the necessary capacity. Much of the flow for both commodities is concentrated in the Panhandle and the Gulf Coast areas of the state.

The elevators-to-feedyards assignment shows that truck trips are most heavily concentrated in the Panhandle. US 385 in the vicinity of Amarillo and Lubbock has the most truck trips, estimated at more than 75,000 per year. Other heavily traveled routes include US 287 from Amarillo to Fort Worth and various state and US highways near Amarillo and Lubbock.

The value of grain sorghum and corn was estimated using October 2016 average prices from the United States Department of Agriculture (USDA) Agricultural Marketing Service. Grain sorghum prices averaged \$2.9041 per bushel (\$5.1859 per hundredweight). Corn prices averaged \$3.4903 per bushel. Since one matrix was prepared for both grain sorghum and corn movement from elevators to feedyards, a weighted average of the prices was used to determine the value of shipments, estimated at \$3.2799 per bushel.

The estimated value (in thousands) of movements on the Texas primary and secondary freight network are displayed in Figure 5.36 (Grain Sorghum Farms to Elevators), Figure 5.37 (Corn Farms to Elevators), and Figure 5.38 (Elevators to Feedyards). The total value of shipments from elevators to feedyards is much greater than shipments from farms to elevators, since both commodities have been combined, and the grain shipped initially to railroad elevators has been offloaded for final truck shipment.

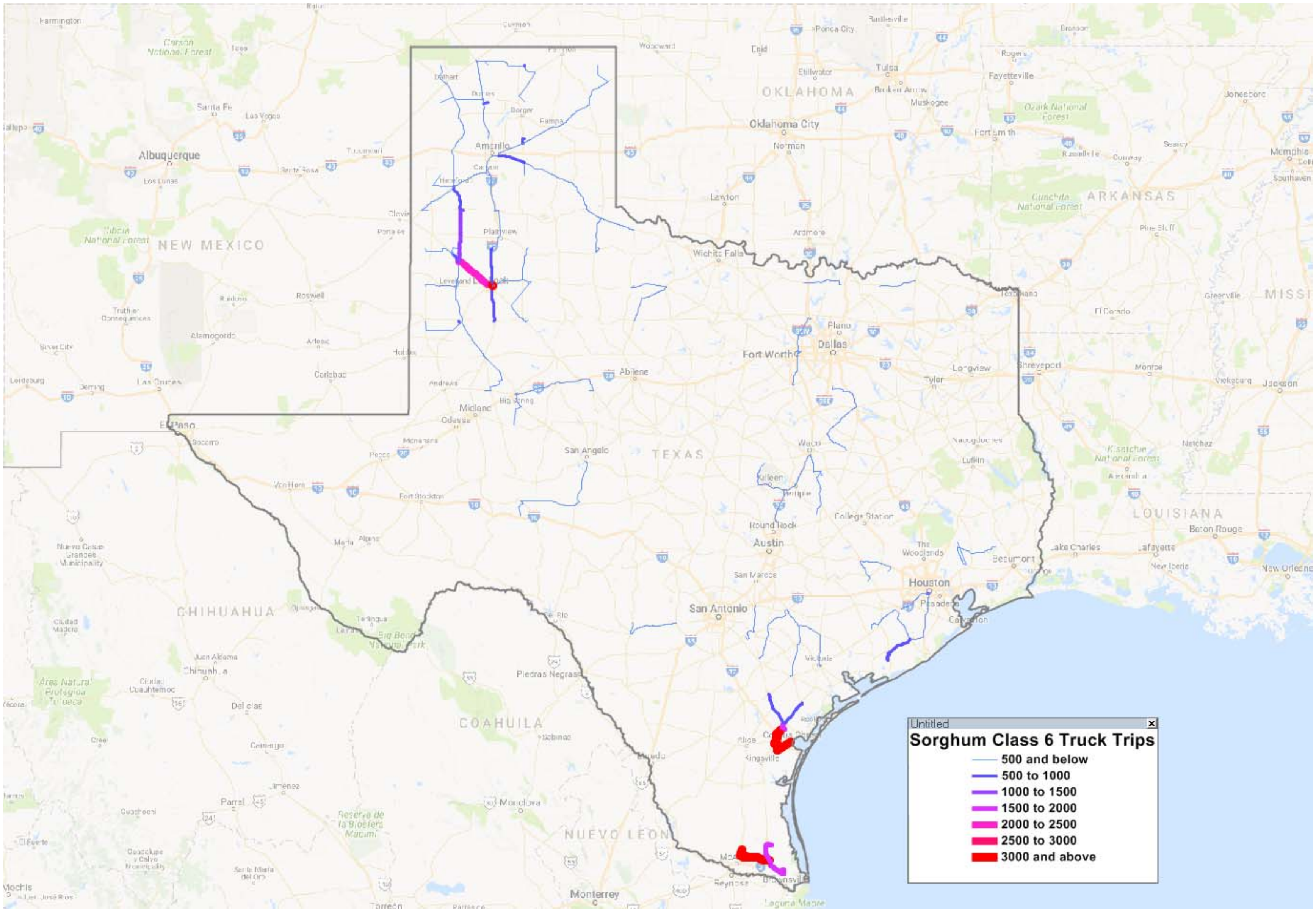


Figure 5.29: Grain Sorghum Class 6 Truck Trips – Farms to Elevators

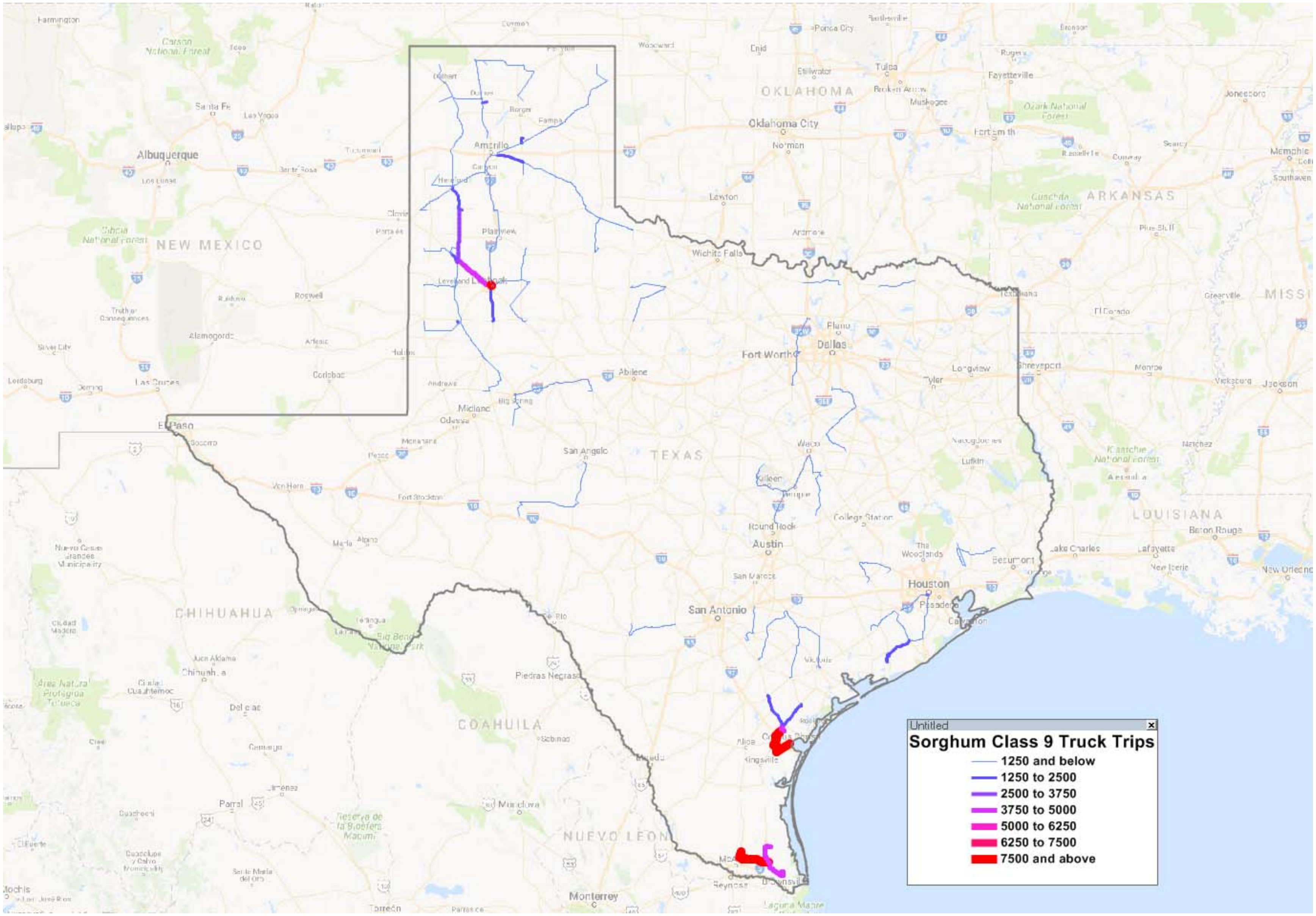


Figure 5.30: Grain Sorghum Class 9 Truck Trips – Farms to Elevators

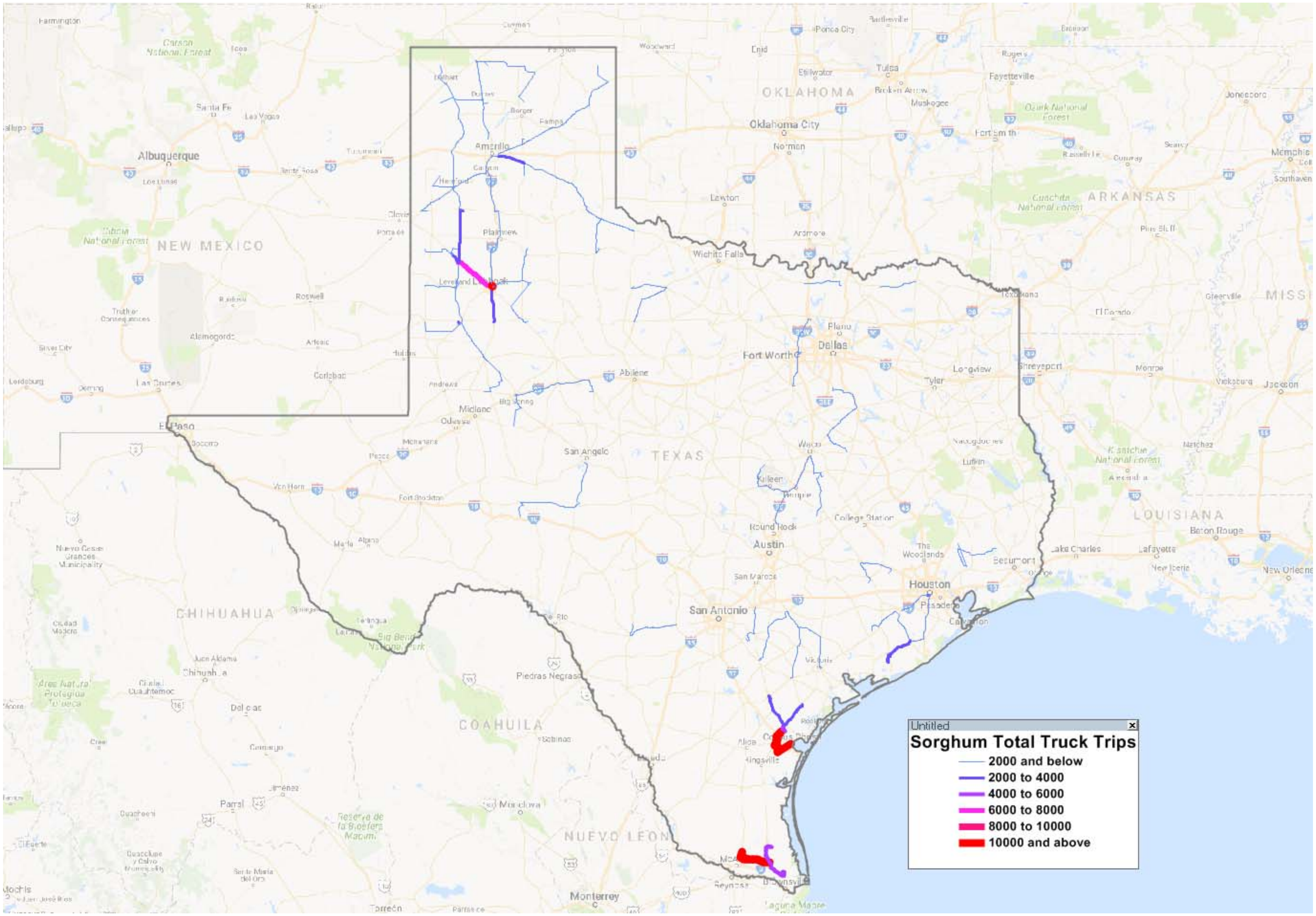


Figure 5.31: Grain Sorghum Total Truck Trips – Farms to Elevators

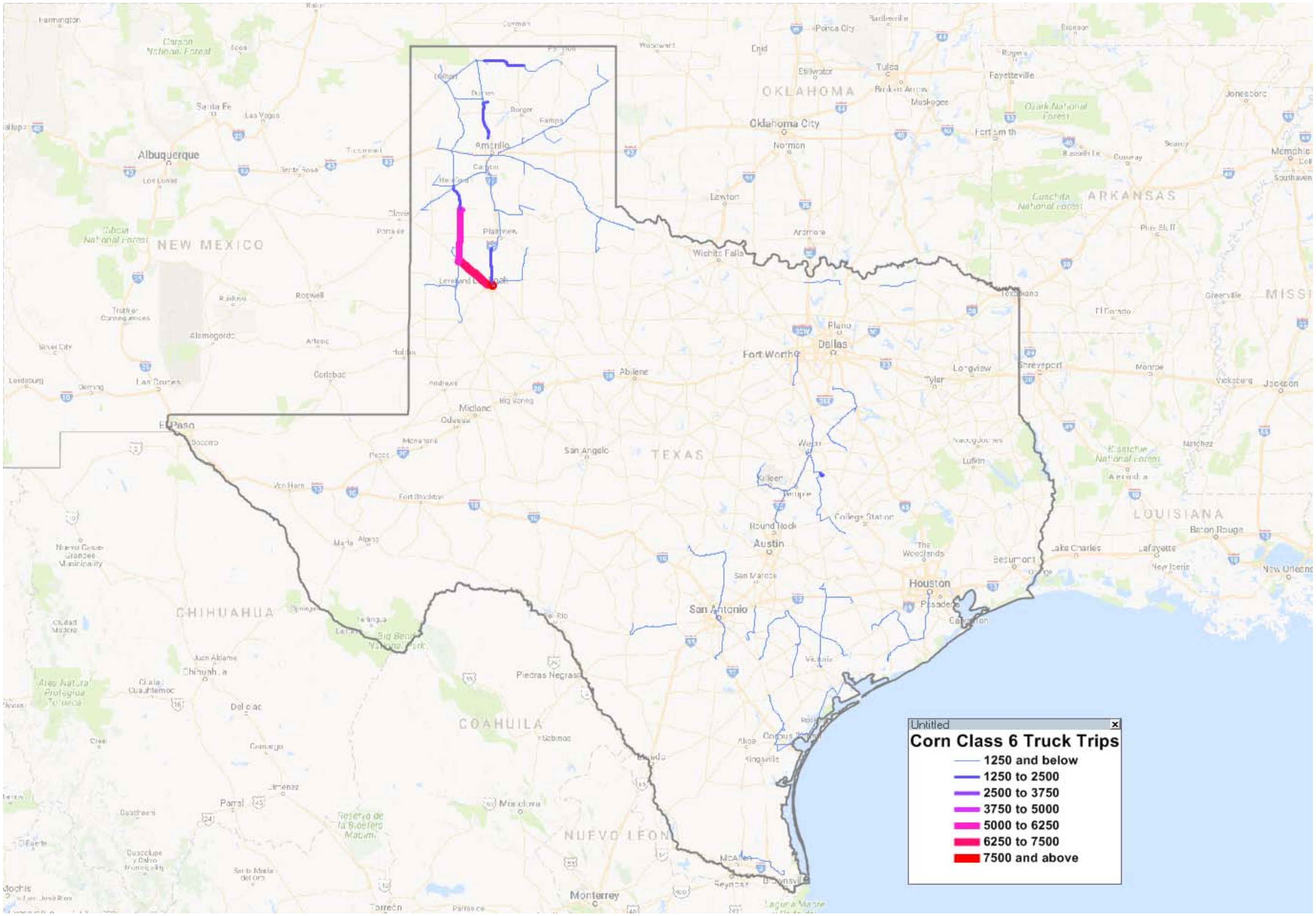


Figure 5.32: Corn Class 6 Truck Trips – Farms to Elevators

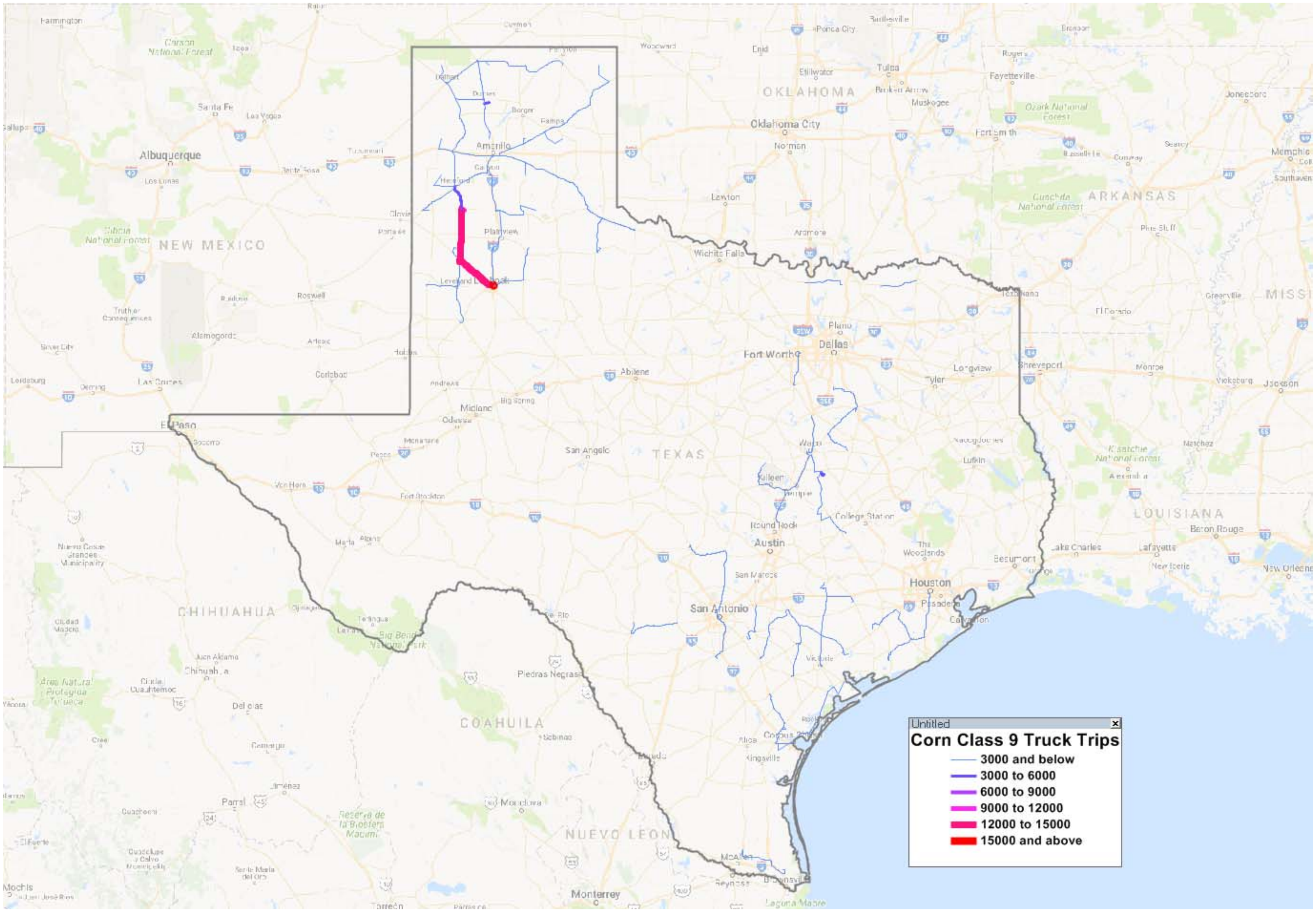


Figure 5.33: Corn Class 9 Truck Trips – Farms to Elevators

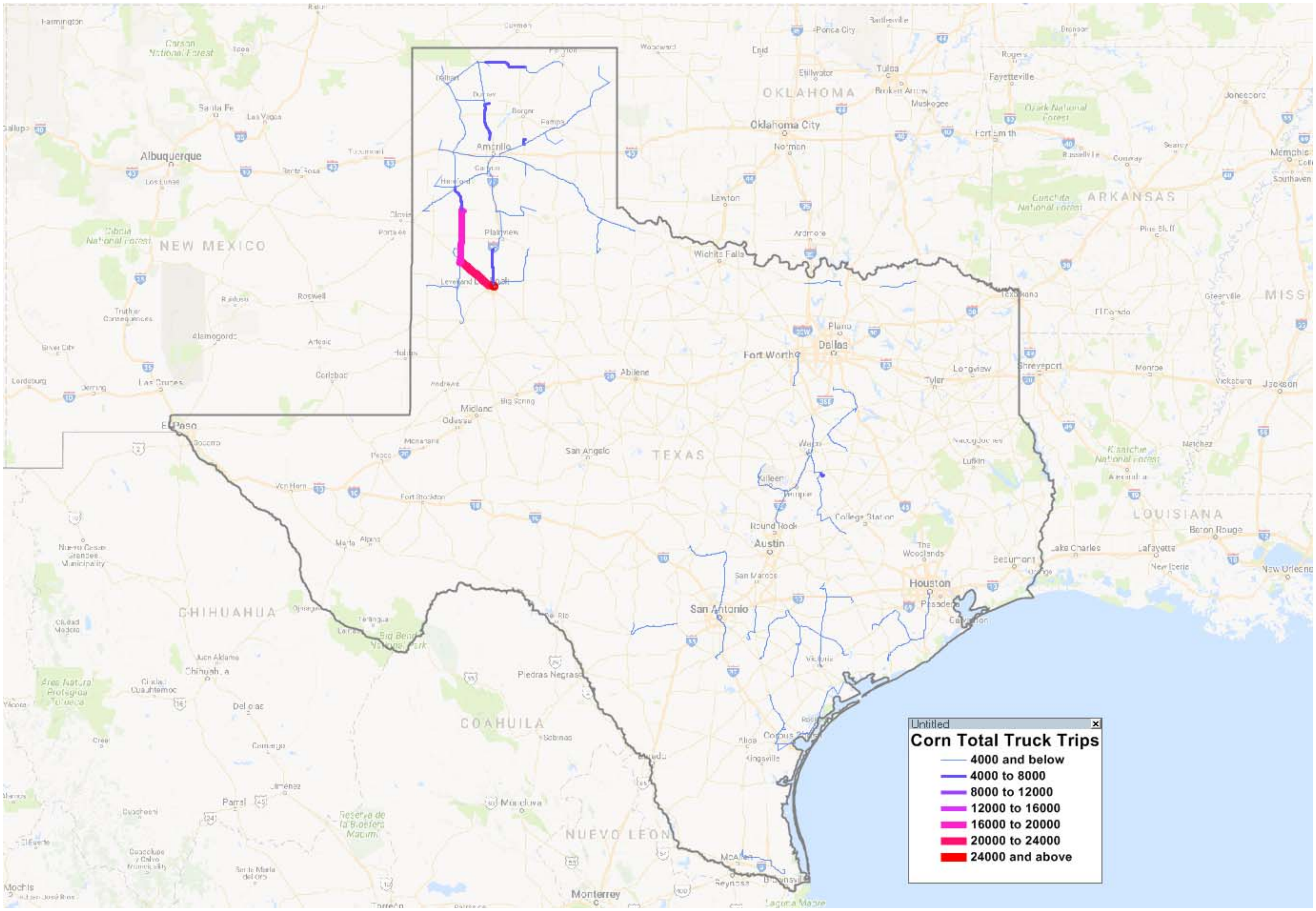


Figure 5.34: Corn Total Truck Trips – Farms to Elevators

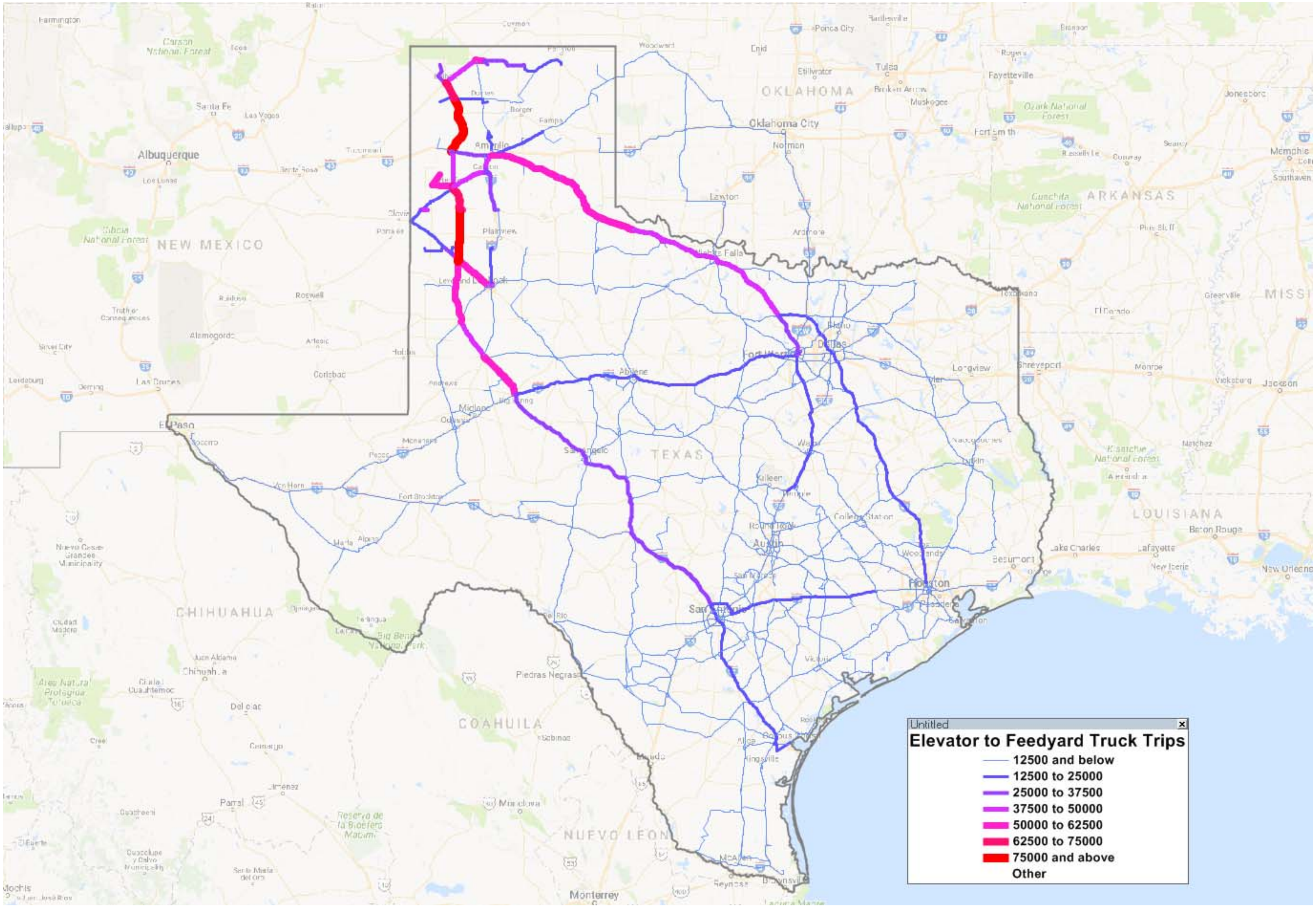


Figure 5.35: Elevators to Feedyards Truck Trips

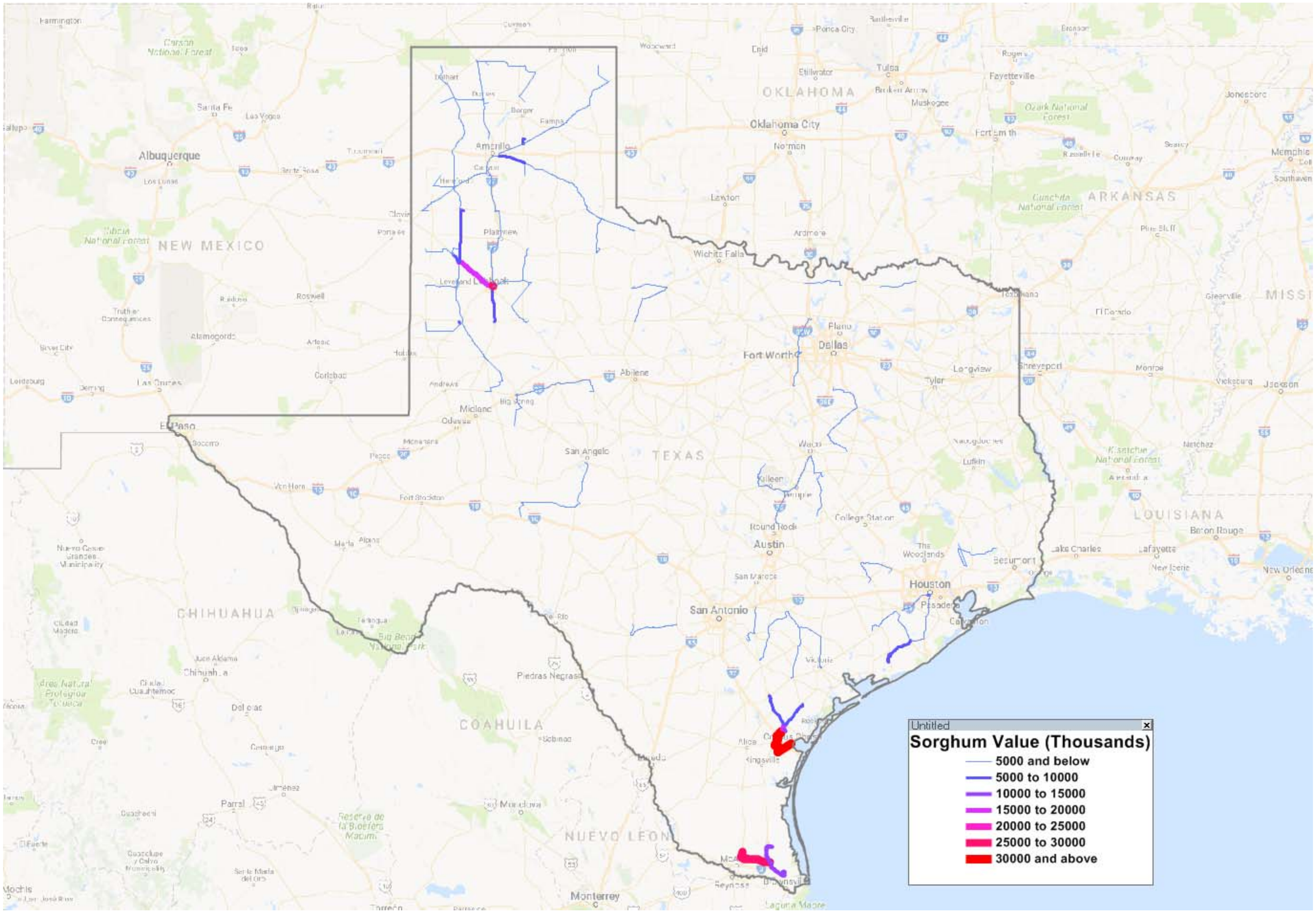


Figure 5.36: Grain Sorghum Value – Farms to Elevators

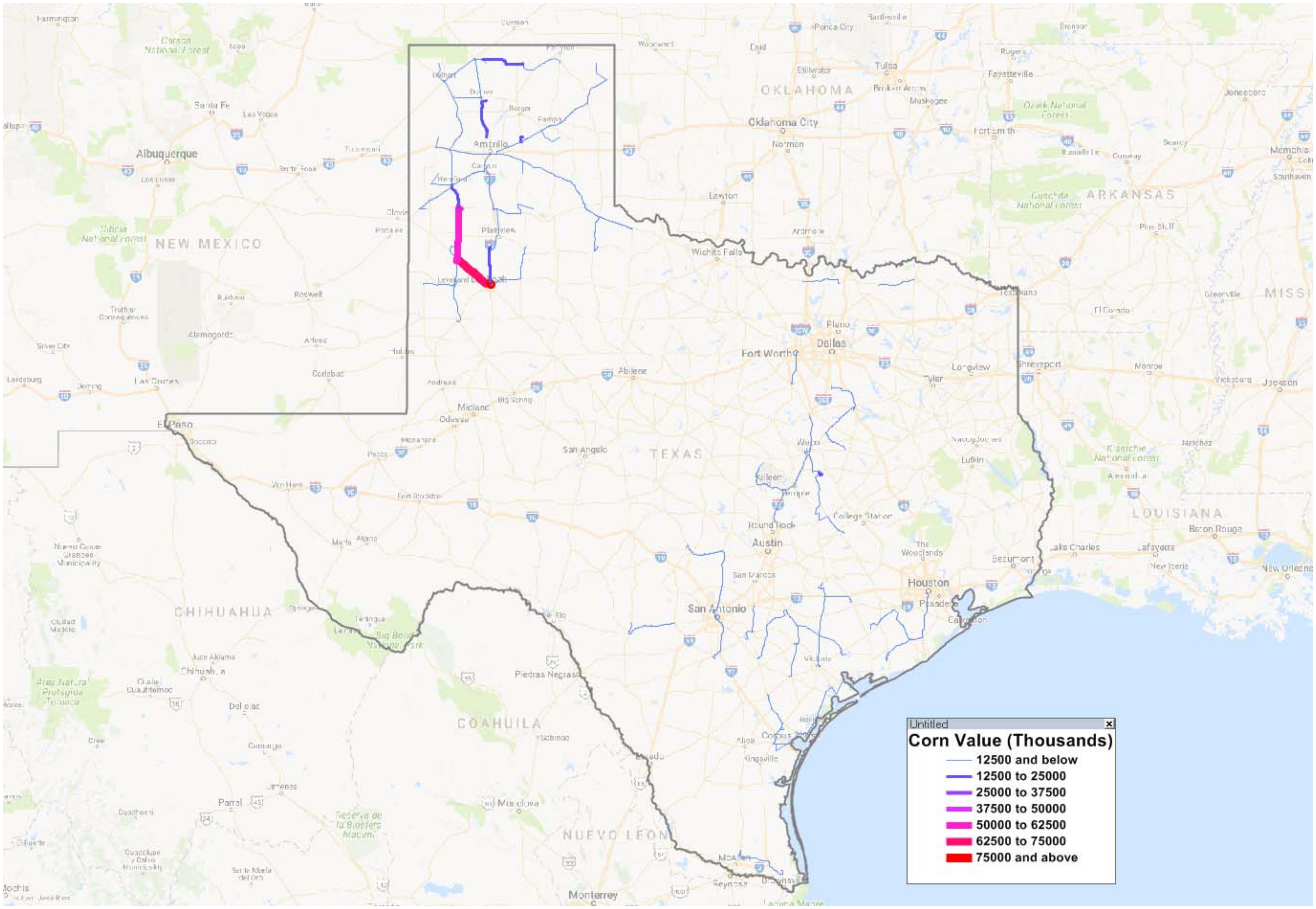


Figure 5.37: Corn Value – Farms to Elevators

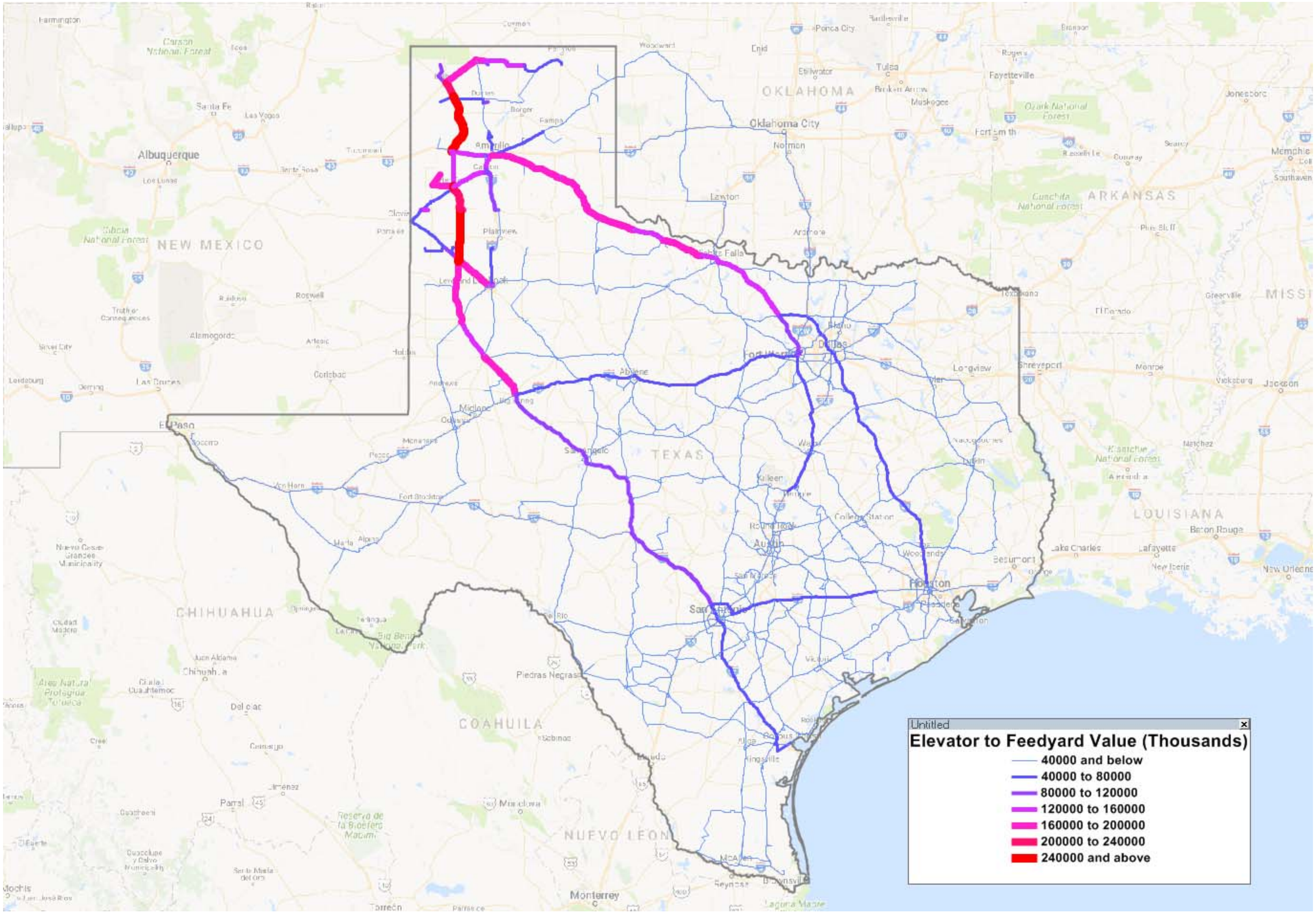


Figure 5.38: Elevators to Feedyards Value

5.2.7 Compare with Transearch Data

As shown in Table 4.1, the closest commodity category to grain sorghum and corn in the Transearch database is grain (STCC 01 13). The research team processed the grain data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.39.

Bases on Transearch data, large grain truck flows are moving between North Texas and Oklahoma. This was not captured by the estimation developed by the research team in this project as this study focused on intrastate commodity movements. A section of US-385 in the Panhandle area also carries high grain truck volume; this is consistent with our estimates (see Figure 5.35). The STCC code 01 13 includes all grains, while in this project we modelled only corn and sorghum, and only their movement from farms to elevators and elevators to feedyards within the state. Thus, it is hard to draw a fair comparison between Transearch data and the estimates developed in this project.

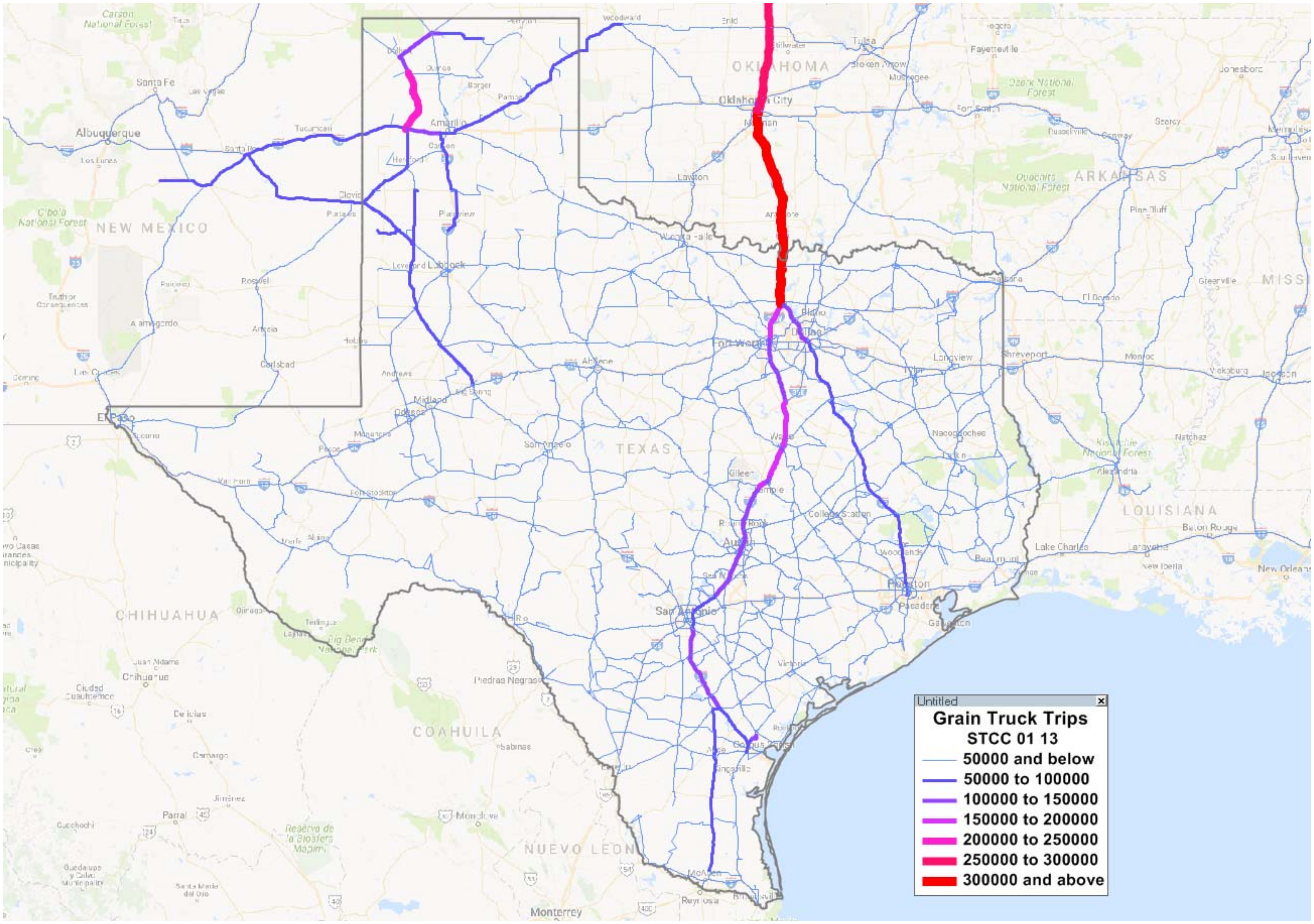


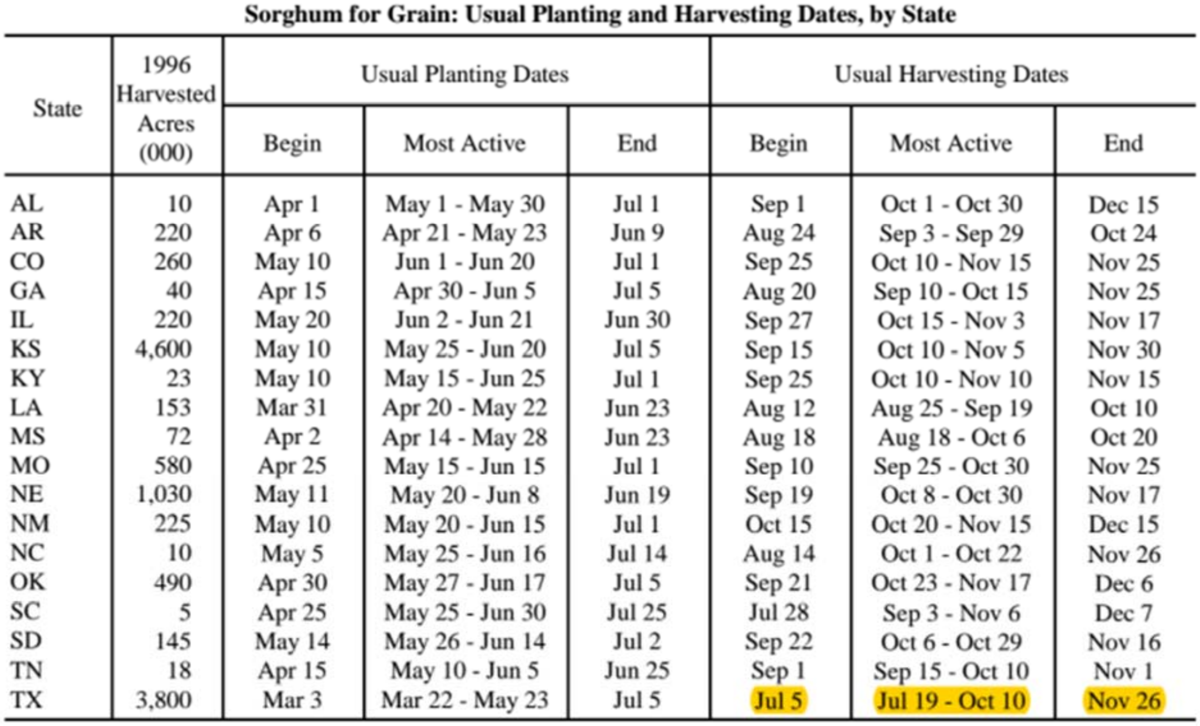
Figure 5.39: Transearch Grain Truck Trips

5.2.8 Seasonal Variation

As mentioned earlier, the transportation of corn and grain sorghum from farms to elevators is mainly for the harvested grain sorghum and corn, since most farms in Texas choose to ship the grain to nearby elevators just after harvest. According to Texas Grain Transportation Study (Fuller, 2001), the further transportation from elevators to feedyards should be based on the demand of feed grain for livestock, poultry, and dairy population.

From Farms to Grain Elevators

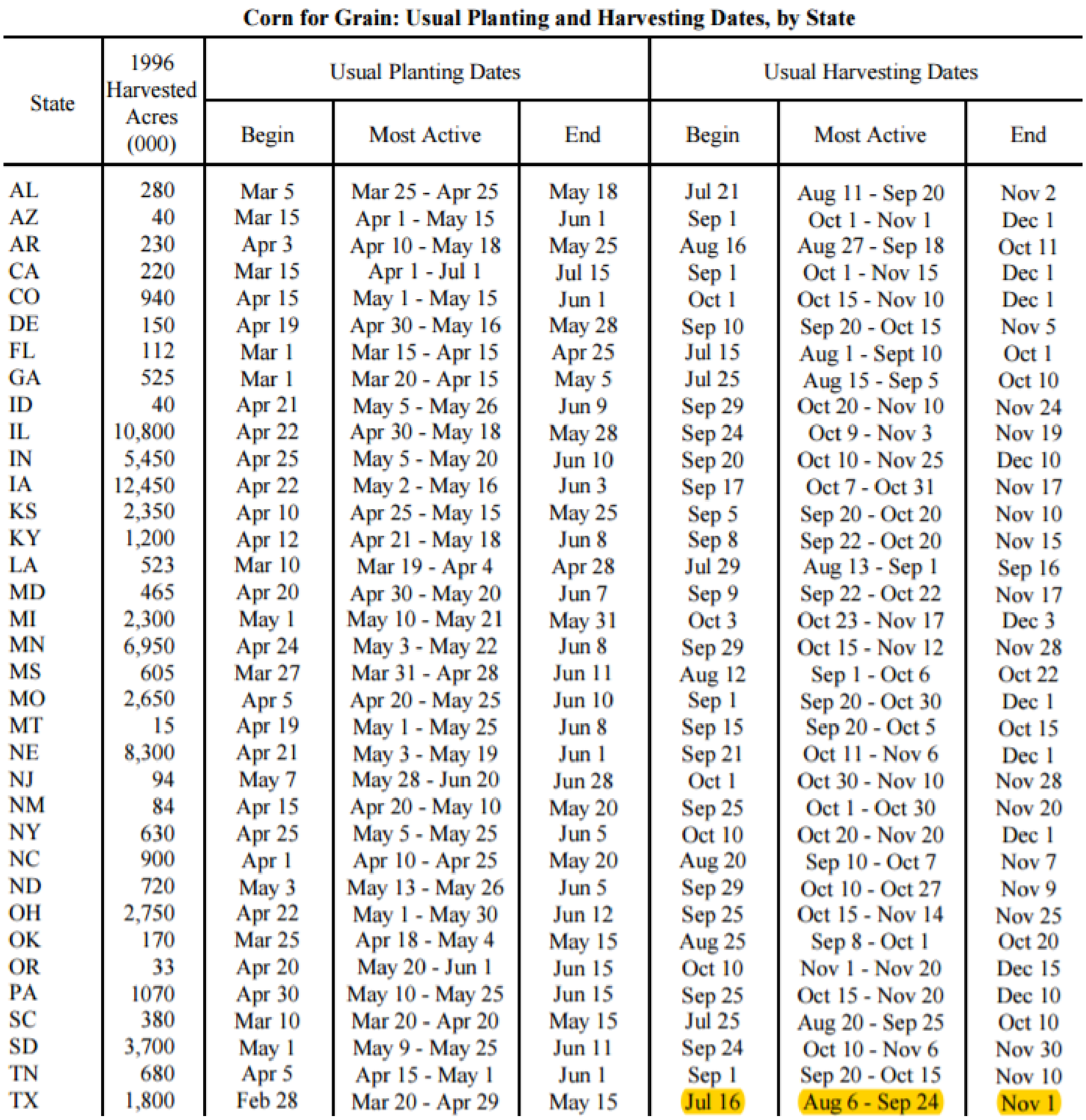
The harvest of grain sorghum and corn does not occur during the entire year, only in some specific months. According to the USDA's report (USDA, 2017), the usual harvesting dates of grain sorghum in Texas start in July and end in November, with the period from July 19 to October 10 as the most active harvesting dates (Figure 5.40). Similarly, the usual harvesting dates for corn in Texas begin in July and end in November, with most active period from mid-July to October (Figure 5.41). The production of harvested grain sorghum and corn was collected from the USDA database (USDA, 2017) and is shown in Figure 5.42 and Figure 5.43. The transportation of sorghum and corn from farms to elevators in Texas has significant seasonal variation as it happens only in the period of July to November.



Sorghum for Grain: Usual Planting and Harvesting Dates, by State

State	1996 Harvested Acres (000)	Usual Planting Dates			Usual Harvesting Dates		
		Begin	Most Active	End	Begin	Most Active	End
AL	10	Apr 1	May 1 - May 30	Jul 1	Sep 1	Oct 1 - Oct 30	Dec 15
AR	220	Apr 6	Apr 21 - May 23	Jun 9	Aug 24	Sep 3 - Sep 29	Oct 24
CO	260	May 10	Jun 1 - Jun 20	Jul 1	Sep 25	Oct 10 - Nov 15	Nov 25
GA	40	Apr 15	Apr 30 - Jun 5	Jul 5	Aug 20	Sep 10 - Oct 15	Nov 25
IL	220	May 20	Jun 2 - Jun 21	Jun 30	Sep 27	Oct 15 - Nov 3	Nov 17
KS	4,600	May 10	May 25 - Jun 20	Jul 5	Sep 15	Oct 10 - Nov 5	Nov 30
KY	23	May 10	May 15 - Jun 25	Jul 1	Sep 25	Oct 10 - Nov 10	Nov 15
LA	153	Mar 31	Apr 20 - May 22	Jun 23	Aug 12	Aug 25 - Sep 19	Oct 10
MS	72	Apr 2	Apr 14 - May 28	Jun 23	Aug 18	Aug 18 - Oct 6	Oct 20
MO	580	Apr 25	May 15 - Jun 15	Jul 1	Sep 10	Sep 25 - Oct 30	Nov 25
NE	1,030	May 11	May 20 - Jun 8	Jun 19	Sep 19	Oct 8 - Oct 30	Nov 17
NM	225	May 10	May 20 - Jun 15	Jul 1	Oct 15	Oct 20 - Nov 15	Dec 15
NC	10	May 5	May 25 - Jun 16	Jul 14	Aug 14	Oct 1 - Oct 22	Nov 26
OK	490	Apr 30	May 27 - Jun 17	Jul 5	Sep 21	Oct 23 - Nov 17	Dec 6
SC	5	Apr 25	May 25 - Jun 30	Jul 25	Jul 28	Sep 3 - Nov 6	Dec 7
SD	145	May 14	May 26 - Jun 14	Jul 2	Sep 22	Oct 6 - Oct 29	Nov 16
TN	18	Apr 15	May 10 - Jun 5	Jun 25	Sep 1	Sep 15 - Oct 10	Nov 1
TX	3,800	Mar 3	Mar 22 - May 23	Jul 5	Jul 5	Jul 19 - Oct 10	Nov 26

Figure 5.40: Sorghum for Grain: Usual Planting and Harvesting Dates, by State



Corn for Grain: Usual Planting and Harvesting Dates, by State

State	1996 Harvested Acres (000)	Usual Planting Dates			Usual Harvesting Dates		
		Begin	Most Active	End	Begin	Most Active	End
AL	280	Mar 5	Mar 25 - Apr 25	May 18	Jul 21	Aug 11 - Sep 20	Nov 2
AZ	40	Mar 15	Apr 1 - May 15	Jun 1	Sep 1	Oct 1 - Nov 1	Dec 1
AR	230	Apr 3	Apr 10 - May 18	May 25	Aug 16	Aug 27 - Sep 18	Oct 11
CA	220	Mar 15	Apr 1 - Jul 1	Jul 15	Sep 1	Oct 1 - Nov 15	Dec 1
CO	940	Apr 15	May 1 - May 15	Jun 1	Oct 1	Oct 15 - Nov 10	Dec 1
DE	150	Apr 19	Apr 30 - May 16	May 28	Sep 10	Sep 20 - Oct 15	Nov 5
FL	112	Mar 1	Mar 15 - Apr 15	Apr 25	Jul 15	Aug 1 - Sept 10	Oct 1
GA	525	Mar 1	Mar 20 - Apr 15	May 5	Jul 25	Aug 15 - Sep 5	Oct 10
ID	40	Apr 21	May 5 - May 26	Jun 9	Sep 29	Oct 20 - Nov 10	Nov 24
IL	10,800	Apr 22	Apr 30 - May 18	May 28	Sep 24	Oct 9 - Nov 3	Nov 19
IN	5,450	Apr 25	May 5 - May 20	Jun 10	Sep 20	Oct 10 - Nov 25	Dec 10
IA	12,450	Apr 22	May 2 - May 16	Jun 3	Sep 17	Oct 7 - Oct 31	Nov 17
KS	2,350	Apr 10	Apr 25 - May 15	May 25	Sep 5	Sep 20 - Oct 20	Nov 10
KY	1,200	Apr 12	Apr 21 - May 18	Jun 8	Sep 8	Sep 22 - Oct 20	Nov 15
LA	523	Mar 10	Mar 19 - Apr 4	Apr 28	Jul 29	Aug 13 - Sep 1	Sep 16
MD	465	Apr 20	Apr 30 - May 20	Jun 7	Sep 9	Sep 22 - Oct 22	Nov 17
MI	2,300	May 1	May 10 - May 21	May 31	Oct 3	Oct 23 - Nov 17	Dec 3
MN	6,950	Apr 24	May 3 - May 22	Jun 8	Sep 29	Oct 15 - Nov 12	Nov 28
MS	605	Mar 27	Mar 31 - Apr 28	Jun 11	Aug 12	Sep 1 - Oct 6	Oct 22
MO	2,650	Apr 5	Apr 20 - May 25	Jun 10	Sep 1	Sep 20 - Oct 30	Dec 1
MT	15	Apr 19	May 1 - May 25	Jun 8	Sep 15	Sep 20 - Oct 5	Oct 15
NE	8,300	Apr 21	May 3 - May 19	Jun 1	Sep 21	Oct 11 - Nov 6	Dec 1
NJ	94	May 7	May 28 - Jun 20	Jun 28	Oct 1	Oct 30 - Nov 10	Nov 28
NM	84	Apr 15	Apr 20 - May 10	May 20	Sep 25	Oct 1 - Oct 30	Nov 20
NY	630	Apr 25	May 5 - May 25	Jun 5	Oct 10	Oct 20 - Nov 20	Dec 1
NC	900	Apr 1	Apr 10 - Apr 25	May 20	Aug 20	Sep 10 - Oct 7	Nov 7
ND	720	May 3	May 13 - May 26	Jun 5	Sep 29	Oct 10 - Oct 27	Nov 9
OH	2,750	Apr 22	May 1 - May 30	Jun 12	Sep 25	Oct 15 - Nov 14	Nov 25
OK	170	Mar 25	Apr 18 - May 4	May 15	Aug 25	Sep 8 - Oct 1	Oct 20
OR	33	Apr 20	May 20 - Jun 1	Jun 15	Oct 10	Nov 1 - Nov 20	Dec 15
PA	1070	Apr 30	May 10 - May 25	Jun 15	Sep 25	Oct 15 - Nov 20	Dec 10
SC	380	Mar 10	Mar 20 - Apr 20	May 15	Jul 25	Aug 20 - Sep 25	Oct 10
SD	3,700	May 1	May 9 - May 25	Jun 11	Sep 24	Oct 10 - Nov 6	Nov 30
TN	680	Apr 5	Apr 15 - May 1	Jun 1	Sep 1	Sep 20 - Oct 15	Nov 10
TX	1,800	Feb 28	Mar 20 - Apr 29	May 15	Jul 16	Aug 6 - Sep 24	Nov 1

Figure 5.41: *Corn for Grain: Usual Planting and Harvesting Dates, by State*

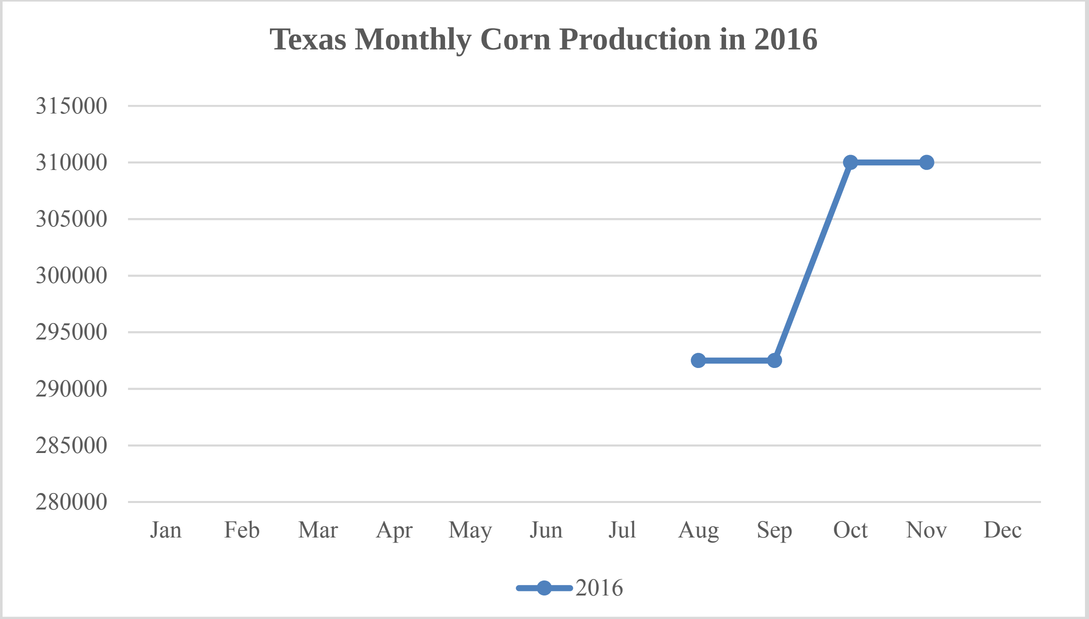


Figure 5.42: Run Sequence Plot of Texas Monthly Corn Production

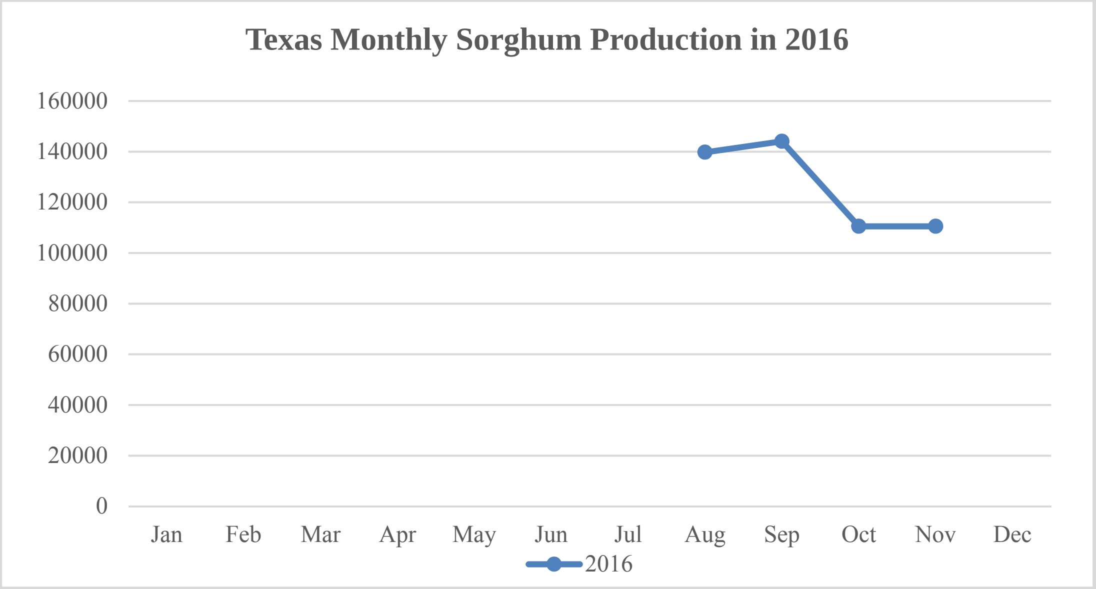


Figure 5.43: Run Sequence Plot of Monthly Grain Sorghum Production in Texas

From Elevators to Feedyards

The research team was able to find national demand for feed grain in different seasons, but not the same for Texas. Based on the USDA's feed grain year book's table (USDA, 2017), the seasonal demand of feed grain from 2013 to 2015 is shown in Figure 5.44. It can be seen from this figure that there is obvious seasonal variation on demand for feed grain. The highest demand generally happens in the fall (September–November) and the lowest demand occurred in summer time (June–August).

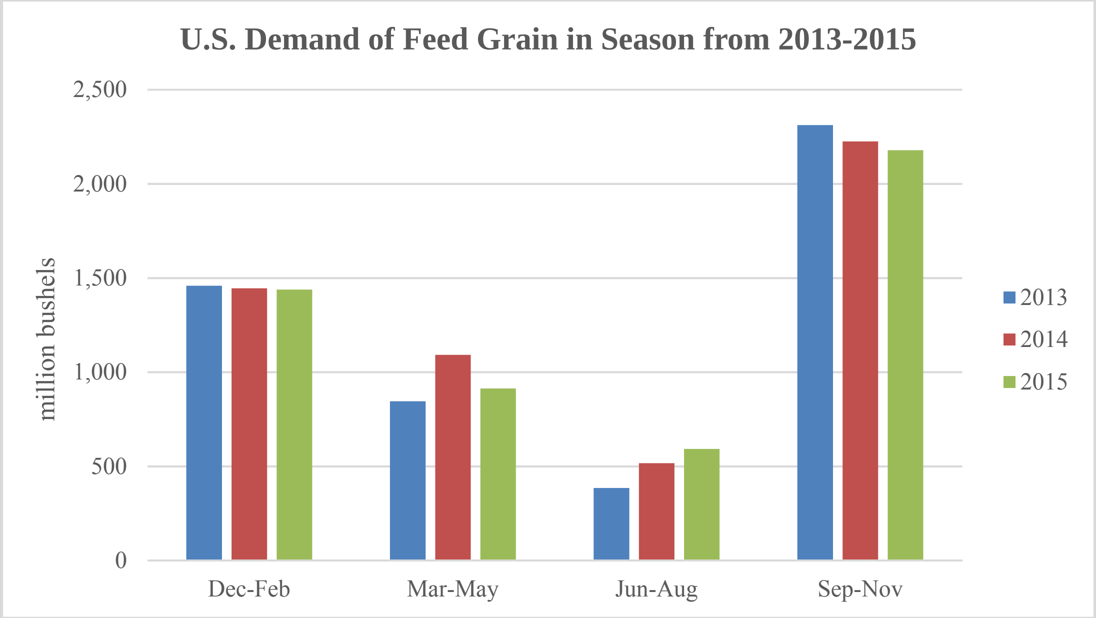


Figure 5.44: U.S. Demand for Feed Grain by Season, 2013–2015

5.2.9 Daily Truck Trip Assignment

Based on the discussion of seasonal variation of the production and consumption of corn and sorghum in previous section, the peak month, percentage of peak month truck trips, and the final monthly truck trips for corn and sorghum at different logistic chain stage can be summarized in Table 5.7.

Table 5.7: Peak month daily truck trips of corn and sorghum

Commodity And Logistic Chain Section	Peak Month(s)	Peak Month Percentage	Annual Truck Trips	Peak Month Daily Truck Trips
Corn (farms to elevators)	October, November	25.7%	210,953	2584
Sorghum (farms to elevators)	September	28.5%	124,706	1618
Corn and Sorghum (elevators to feedyards)	October, November, December	14.2%	407,815	2758

These peak month daily truck trips are assigned to the network. Their distributions on the network are presented and discussed below.

Corn (Farms to Elevators)

Corn is mainly moved from farms to elevators during the four months from August to November. Activities in October and November are slightly higher than August and September.

Figure 5.45 shows the distribution of farm-to-elevator daily corn truck trips in October. Again, the overall pattern is similar to what was estimated earlier without considering impact of congestion (see Figure 5.34), but some changes can be observed. For example, the trip from Austin to the Fredericksburg area shifted to San Antonio (check Figure 5.34). This reflects the impact of congestion on the trip distribution.

Grain Sorghum (Farms to Elevators)

Similar to corn, grain sorghum is also mainly moved from farms to elevators during the four months from August to November. Based on the data discussed in Section 5.2.8, more movements happen in August and September, with September's level of activity slightly higher than August's. Therefore, September daily truck trips were assigned to the network. The results are shown in Figure 5.46. Like corn, the overall pattern is similar to what was developed in section 5.2.6 when impact of congestion was not considered (see Figure 5.31). This is mainly because both corn and sorghum's movement from farms to elevators are short local trips. The spatially closest elevator from a farm is also usually the nearest one in terms of travel time. But as with corn, some changes in trip origins and/or destinations and routes can still be observed that reflect the impact of travel times.

Corn and Sorghum (Elevators to Feedyards)

Once corn and sorghum are stored in elevators, they can be moved to feedyards any time of the year. Based on the data discussed in Section 5.2.8, the movement of corn and sorghum from elevators to feedyards happens most in October, November, and December. The distribution of daily truck trips moving corn and sorghum from elevators to feedyards in October is shown in Figure 5.47. Some notable changes can be observed between Figure 5.47 and the results developed without considering the impact of congestion in Section 5.2.6 (see Figure 5.35)—for example, fewer truck trips using IH 45 between Dallas and Houston. Instead, the trips are more spread out on various alternative routes between these two cities. The trip from Fort Worth to Temple is also more spread out rather than concentrated on IH 35. These changes reflect the impact of congestion on commodities' route choices.

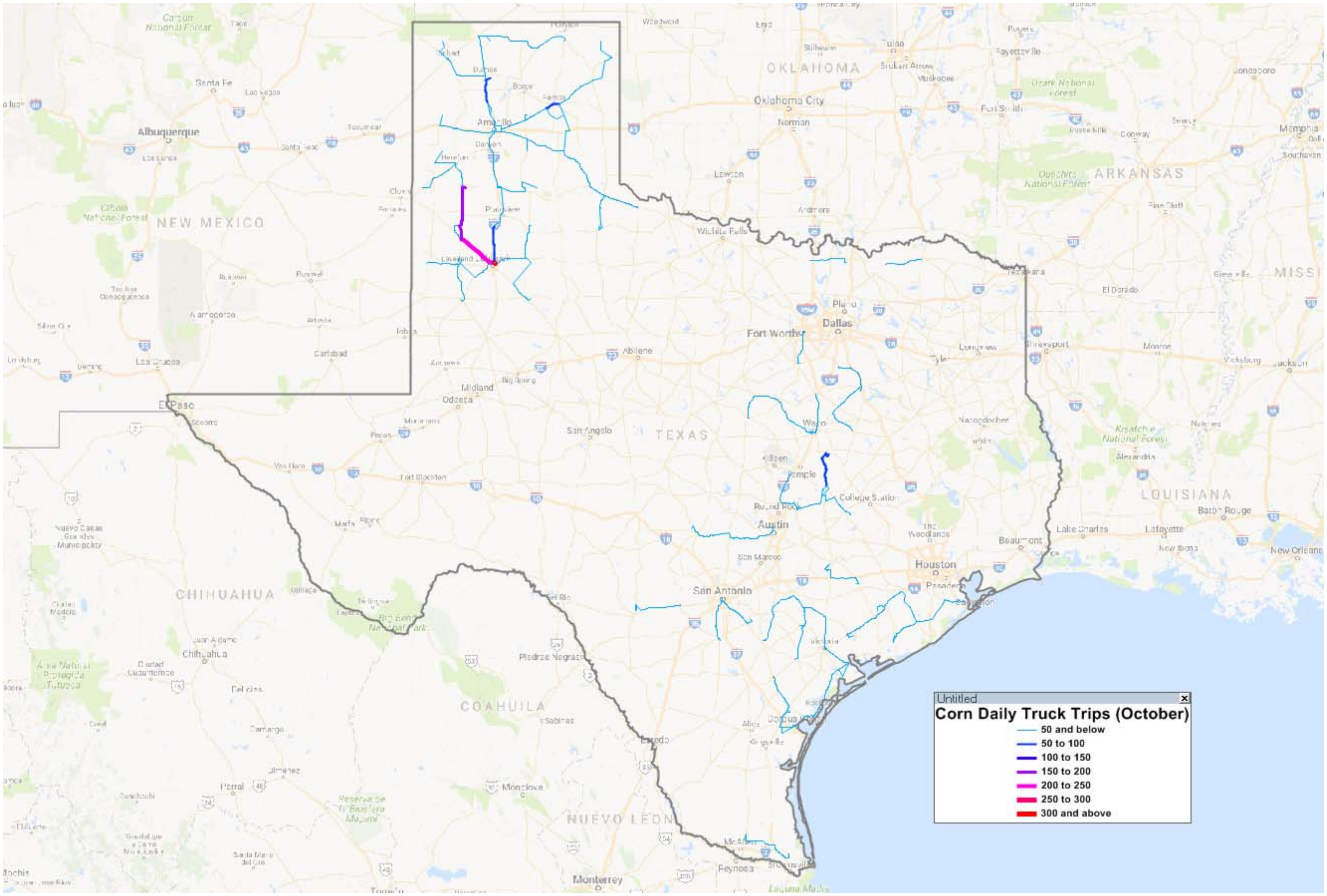


Figure 5.45: Corn Daily Truck Trips from Farms to Elevators in October

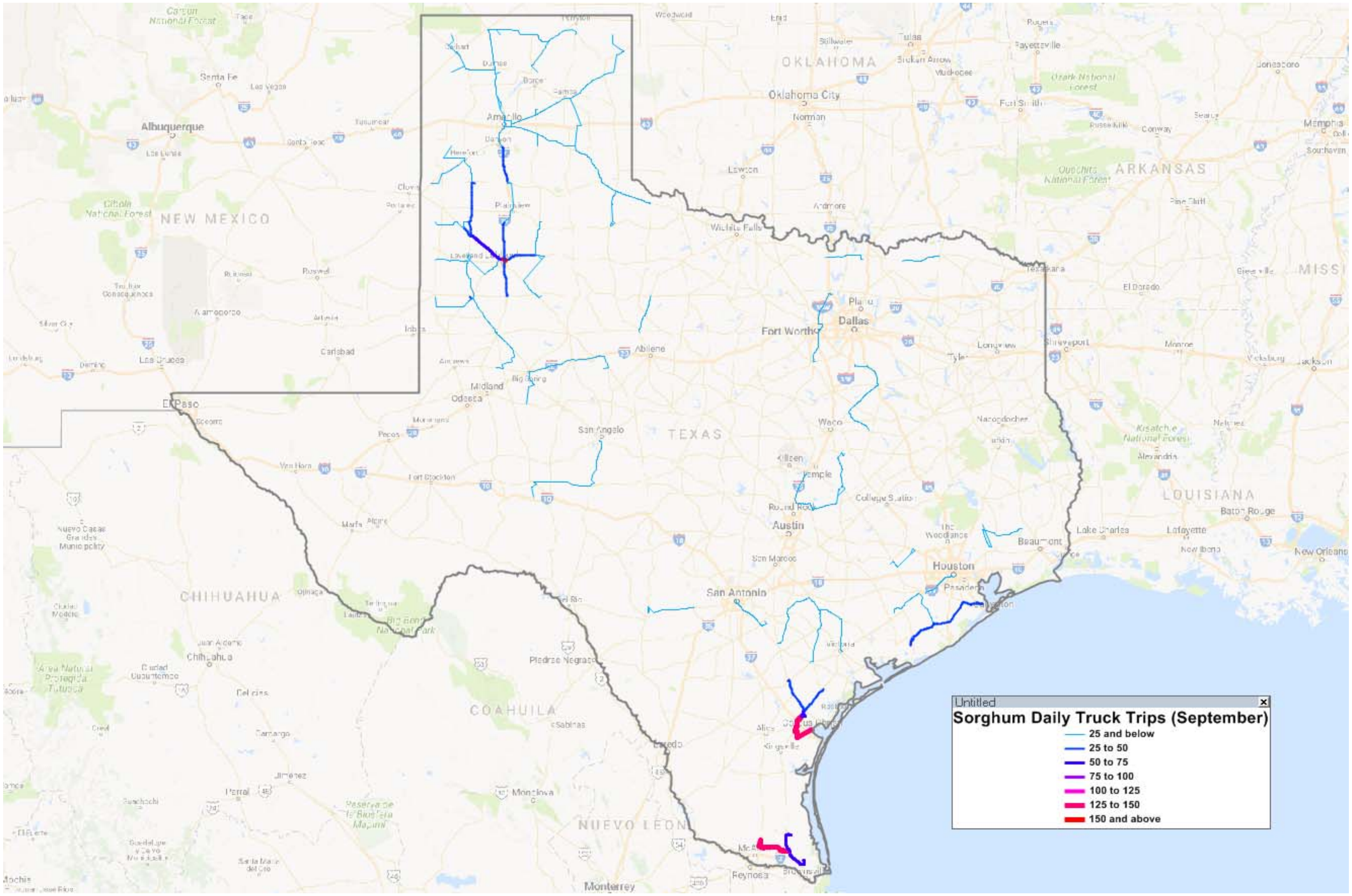


Figure 5.46: Sorghum Daily Truck Trips from Farms to Elevators in September

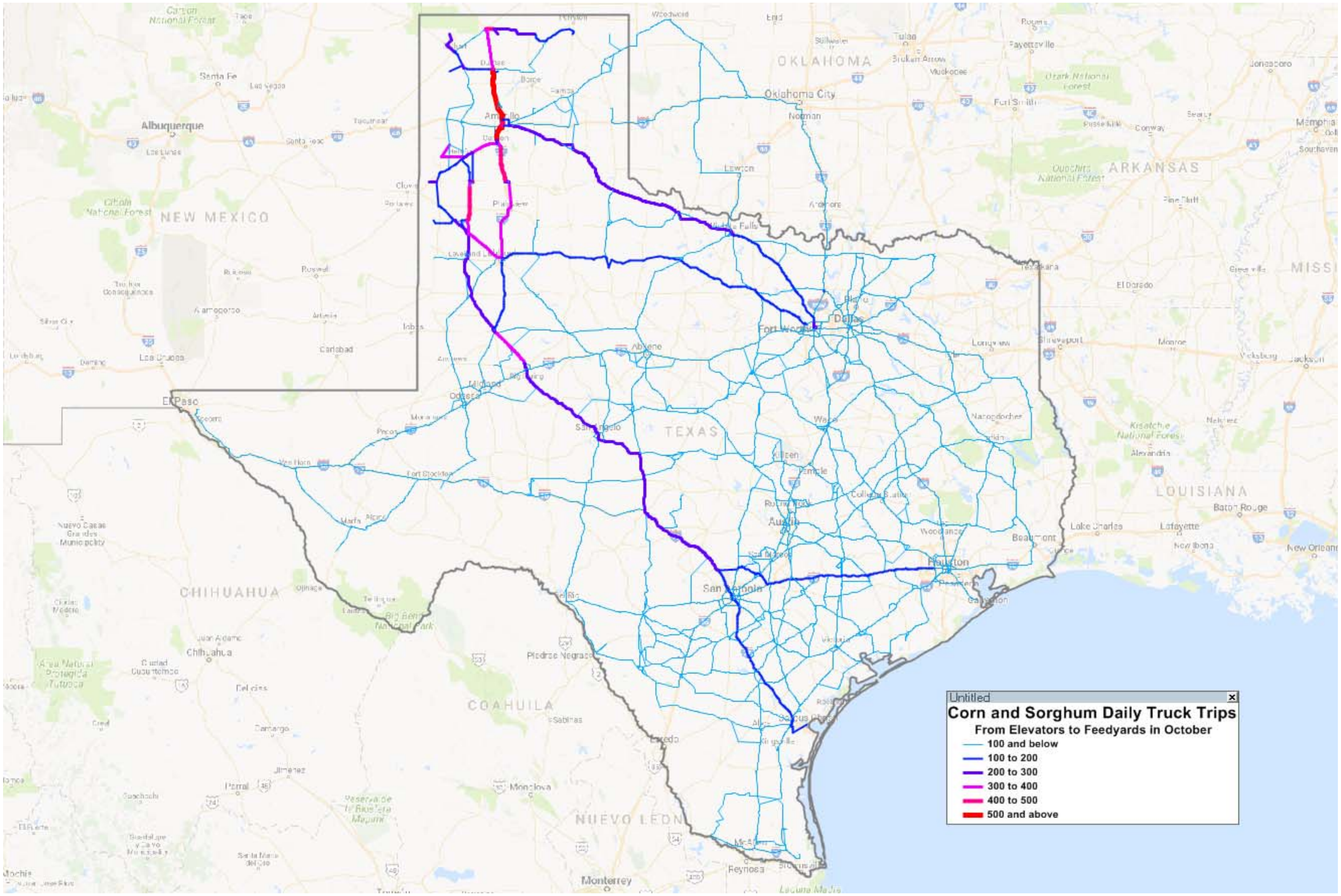


Figure 5.47: Corn and Sorghum Total Daily Truck Trips from Elevators to Feedyards in October

5.2.10 Summary

Grain sorghum and corn are very important commodities that provide the backbone of the Texas cattle industry. Although Texas produces over 450 million bushels of these commodities, there is still a grain deficit within the state, leading to many imports of grain from other Midwestern states by rail.

The research team utilized USDA county production estimates within the state, TWC and BNSF-identified grain elevators, and TCEQ cattle feedyard permit data to estimate the flow of grain sorghum and corn from Texas farms to elevators and then from elevators to cattle feedyards. Because a majority of farms, elevators, and feedyards are located in the Texas Panhandle, the flows within the state are dominated by local shipments within the Panhandle counties.

Grain sorghum and corn are agricultural products with significant seasonal variations. They are harvested and transported to elevators during fall. Their consumption by feedyards peaks in winter months.

5.3 Broilers

5.3.1 Background

According to the USDA (2015), in 2013 the United States produced a total of 8.53 billion broilers, equating to 50.68 billion lbs of broilers. The total value of production of these broilers was $30.76 billion, or $3.60 per broiler. On average, broilers weighed 5.94 lb/head and the value of production was $0.61/lb.

Nineteen states, one of which is Texas, combined to produce more than 96% of the total broilers produced in the US. The majority of these 19 states are from the southeast region but also all along the Atlantic coast up to Pennsylvania. The most notable exception is California.

In 2013, Texas produced 610.1 million broilers, which was about 7% of total US production. Although Texas is one of the major broiler producers, it still has to import many broilers from the east, as much of Texas' broiler production is exported either to another state in the north and west or to another country via El Paso, Laredo, or Houston.

Indeed, if one considers the amount of broilers exported internationally by each state as part of the demand that that state has to satisfy, then in order to meet its demand, Texas imports more broilers from other states than it exports to other states. Figure 5.48 shows the states whose broiler production exceeds their international exports plus the demand to satisfy their own population. All other states import more broilers than they export to other states. This includes Texas, albeit Texas is one of the rare states that must import many broilers only because it exports so much to other countries.

Figure 5.48: States That Are Able to Satisfy the Entire Demand for All of Their International Exports plus Their Population

In this analysis, the research team did not differentiate between different broiler parts having different values per pound, since splitting a broiler up into multiple parts creates data that is much disaggregated and may result in large errors. In addition, data on the production and consumption of specific broiler parts is hardly available. Indeed, the only source found that does differentiate between different broiler parts is USA Trade Online, a tool provided by the US Census Bureau.

5.3.2 Supply Chain

From the parent breeding stocks to distribution of ready cook broiler meat, there is a total of seven steps in the supply chain. Currently, most large broiler companies are vertically integrated so that usually they are in control of all seven steps. The seven steps are as follows:

1. **Pullet breeding farms:** These farms provide parent breeding stock. They are solely responsible for laying eggs to create pullets (i.e., young hens). Then, in step 3, when the pullets are sexually mature, they will produce the chickens to be used for broiler meat.
2. **Pullet farms:** After hatching, the young chicks will be transported to a pullet farm where they are raised for roughly 20 weeks before they become ready to start laying eggs.
3. **Breeder farms:** As the pullets approach sexual maturity, they are transferred to breeder farms where they will start laying eggs.
4. **Hatcheries:** The eggs are transferred to a hatchery for roughly 3 weeks until they hatch.
5. **Broiler farms:** Once the eggs have hatched, the chicks are transported to broiler farms where they are raised for 6 to 7 weeks. In order to maximize efficiency, extreme care is taken to make sure that the chicks stay healthy and that they are fed the correct diet that

will allow them to grow as fast and as large as possible. In fact, according to a study by Zuidhof et al. (2014), a fully grown broiler today is more than twice the size of a fully grown broiler from 1978 and more than four times the size of a fully grown broiler from 1957. Many big broiler companies do not own most of their broiler farms but instead work with contract farmers. This means that they provide hatched eggs, as well as the feed and anything else that may be needed, but the contract farmers are responsible for raising them to their target weight. Then, the contract farmers hand them back over to the broiler company for processing (National Chicken Council, 2015).

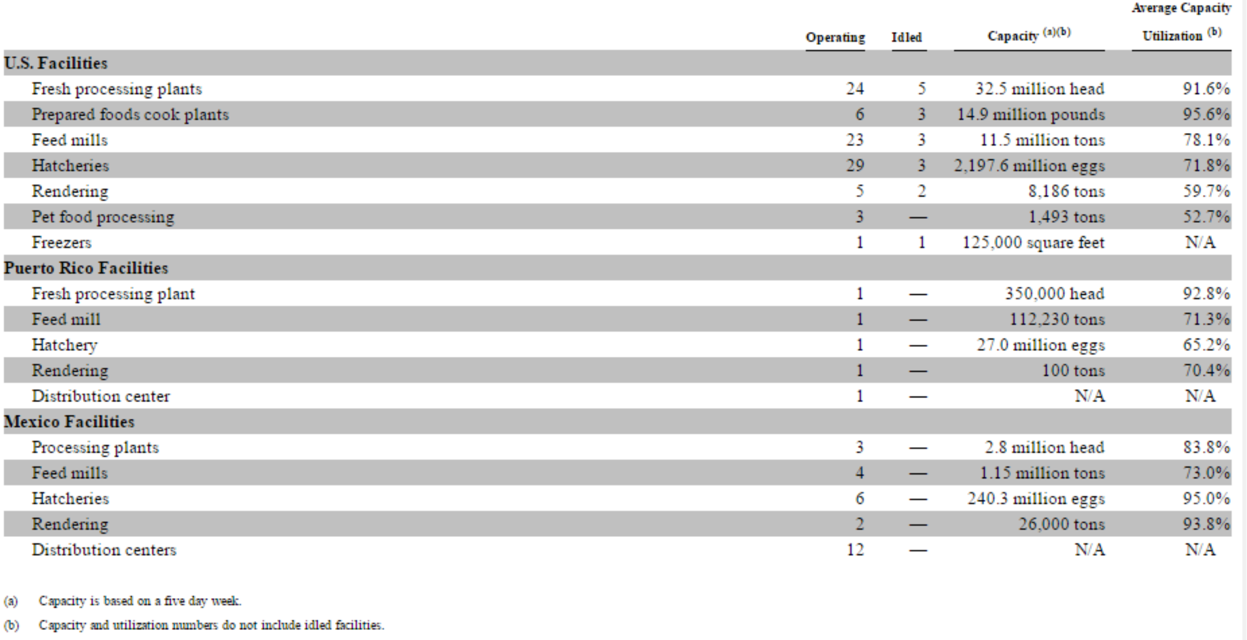
6. **Processing plants:** After having becoming fully grown, the broilers are transported from the broiler farms to poultry processing plants where they are fully prepared so that they are ready to cook or to be used in a secondary processing facility for more specific products. Usually, the processing plants are strategically placed so that they are in the vicinity of the broiler farms so as to minimize the cost of transport. Thus, in Texas, the broiler processing plants are all located in the eastern half of the state.
7. **Distribution:** After processing, the broilers can either be further processed at a secondary processing facility or they can be distributed for consumption to retail, wholesalers, restaurants, etc. If they are taken for secondary processing—about 9% of the time (National Chicken Council, 2013)—they will be distributed for consumption once secondary processing is completed.

Between steps 2 and 5, feed mills, which are owned and operated by the broiler company, are always active in providing each step of the supply chain with the required feed type. These feed mills are usually very close to the farms and processing plants. Figure 5.49 illustrates the broiler supply chain as used by Tyson Foods, Inc. (Jones, 2014). Most large broiler companies use very similar processes.

Figure 5.49: A Broiler Supply Chain Used by Tyson Foods

Since the entire supply chain takes about 9 months from the moment a pullet is born to the time that a broiler is processed, adjusting the amount of a company's supply will take at least 9 months. Thus, it is possible to predict broiler supply 9 months in advance if data on the amount of pullets being laid is available.

The locations and capacities of each type of farm (pullet farm, breeder farm, hatcheries, and broiler farms) are very difficult to find. Simply put, there are too many farms to be able to keep track of each of them since information about these farms is not publicly available. Texas alone has between 2,000 to 3,000 broiler farms. Most of these farms are contracted by the broiler companies, but broiler companies are under no obligation to reveal anything with regards to their farms in their financial statements, such as Form 10-K of publicly traded broiler companies that is provided by the US Securities and Exchange Commission. Figure 5.50 provides an example of the information reported in Form 10-K. Note that no information with regards to farms is reported. Thus, due to a lack of publicly available information for steps 1 to 5 in the broiler supply chain, the research team focused on the supply chain between step 6 (processing plants) and step 7 (distribution).



	Operating	Idled	Capacity [a][b]	Average Capacity Utilization [b]
U.S. Facilities				
Fresh processing plants	24	5	32.5 million head	91.6%
Prepared foods cook plants	6	3	14.9 million pounds	95.6%
Feed mills	23	3	11.5 million tons	78.1%
Hatcheries	29	3	2,197.6 million eggs	71.8%
Rendering	5	2	8,186 tons	59.7%
Pet food processing	3	—	1,493 tons	52.7%
Freezers	1	1	125,000 square feet	N/A
Puerto Rico Facilities				
Fresh processing plant	1	—	350,000 head	92.8%
Feed mill	1	—	112,230 tons	71.3%
Hatchery	1	—	27.0 million eggs	65.2%
Rendering	1	—	100 tons	70.4%
Distribution center	1	—	N/A	N/A
Mexico Facilities				
Processing plants	3	—	2.8 million head	83.8%
Feed mills	4	—	1.15 million tons	73.0%
Hatcheries	6	—	240.3 million eggs	95.0%
Rendering	2	—	26,000 tons	93.8%
Distribution centers	12	—	N/A	N/A

(a) Capacity is based on a five day week.

(b) Capacity and utilization numbers do not include idled facilities.

Figure 5.50: Excerpt of Form 10-K provided by Pilgrim's Pride to US Securities and Exchange Commission for 2013

In addition, the research team decided not to focus secondary/further processing plants that may be a part of step 6, for a variety of main reasons. First, the amount of broilers that goes to secondary processing is a small portion of the entire broiler industry, only about 9% (National Chicken Council, 2013). Second, there is no clear-cut value to be used as "the added value of a broiler" after it comes out of a secondary processing plant due to a plethora of products that may result.

Third, it is believed that two out of the four main broiler companies in Texas do not partake in secondary processing at all. The first of these two, Holmes Food, has only one processing facility in which they only do primary processing. After this, the broilers are sold to wholesalers and distributors who may decide to take it elsewhere for further processing. The second of these two, Sanderson Farms, has only one secondary processing plant, which is in Flowood, Mississippi, and has primary processing plants that are much closer to this secondary processing plant than the ones in Texas (Sanderson Farms, 2016). Thus, it would make sense that any secondary processing that Sanderson Farms performs is not associated with its broiler production in Texas.

Fourth, in Texas, Pilgrim's Pride has two secondary processing plants. While the first one is in Waco (farther from its primary processing plants), the second one is in Mount Pleasant, sharing the same campus as the primary processing plant located there. Thus, the Mount Pleasant facility does not allow for differentiating between primary and secondary processing.

Last, Tyson Foods is not only a broiler company but also a beef and pork company. On their website, they provide the names of all of their facilities. In Texas alone, they list 44 facilities (Tyson Foods, Inc., 2014). Unfortunately, it is not clear which of these facilities work in which industry (broilers, cattle, or pigs). Thus, rather than mistakenly route broilers to the wrong facility, the research team took the more conservative approach of focusing only on primary processing.

5.3.3 Datasets

Throughout the entire modeling stage devoted to developing an OD Matrix, a plethora of different sources were considered, some of which are mentioned here. However, in the end, most of the sources were not used in the final analysis because they were not able to provide information for the entire industry or the entire state. Instead, often, they may have only provided information with regards to one company or region. Alternatively, information provided by these sources may not have been complete or accurate.

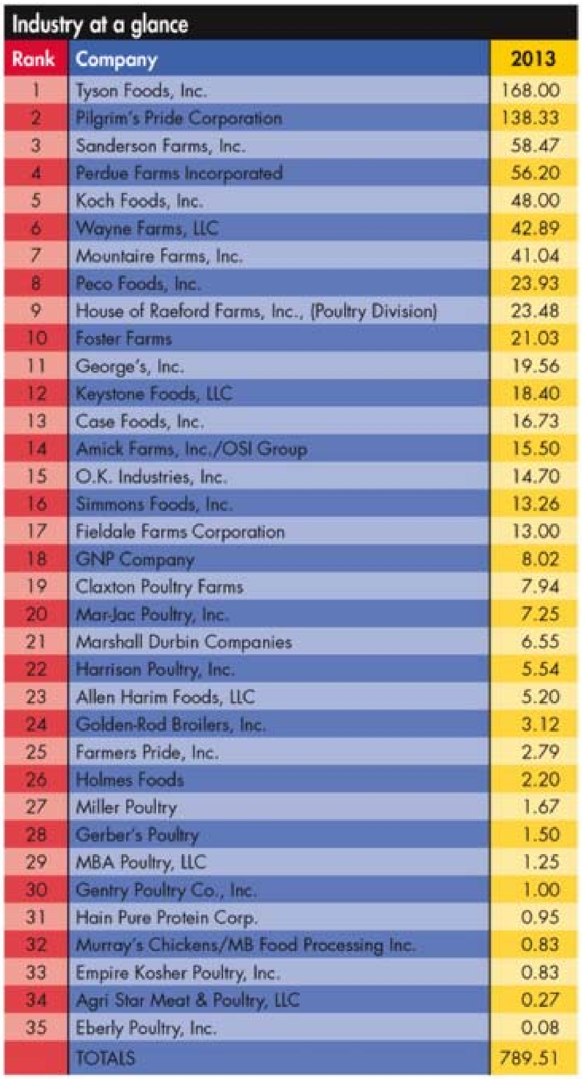
Socrates

The first dataset used was the Texas business dataset Socrates that is provided by the TWC. Socrates was a valuable instrument in helping the research team understand where much of the broiler activity was going on. However, the data reported by Socrates was often inaccurate or did not report specifically the type of information that the research is interested in. For example, some broiler processing plants, such as the Sanderson Farms processing plants in Waco and Palestine, were not found in Socrates. Only because of the fact that industry experts advised that there should be "around a dozen" broiler processing plants in Texas did the research team continue to search for more locations when they were not found in Socrates.

Generally, the NAICS code used in Socrates to find broiler processing plants was 3116. This is an issue because this NAICS code is associated with all types of animal slaughter/processing and not only broilers. Thus, Socrates returns a total of 259 businesses that are associated with this NAICS code and careful examination is required to determine what sort of animal is actually processed by each of these companies.

WATT Poultry Report

A dataset that proved to be useful in terms of validating information, but was not instrumental in actual modeling, was provided by the *WATT Poultry Report* (2014). In this report, WATT Poultry gives a brief summary of many of the major stakeholders in the broiler industry. More importantly, they provide information with regards to how many pounds of broilers each of the top 35 broiler companies in the US processed in 2013 as shown in Figure 5.51.



Industry at a glance

Rank	Company	2013
1	Tyson Foods, Inc.	168.00
2	Pilgrim's Pride Corporation	138.33
3	Sanderson Farms, Inc.	58.47
4	Perdue Farms Incorporated	56.20
5	Koch Foods, Inc.	48.00
6	Wayne Farms, LLC	42.89
7	Mountaire Farms, Inc.	41.04
8	Peco Foods, Inc.	23.93
9	House of Raeford Farms, Inc., (Poultry Division)	23.48
10	Foster Farms	21.03
11	George's, Inc.	19.56
12	Keystone Foods, LLC	18.40
13	Case Foods, Inc.	16.73
14	Amick Farms, Inc./OSI Group	15.50
15	O.K. Industries, Inc.	14.70
16	Simmons Foods, Inc.	13.26
17	Fieldale Farms Corporation	13.00
18	GNP Company	8.02
19	Claxton Poultry Farms	7.94
20	Mar-Jac Poultry, Inc.	7.25
21	Marshall Durbin Companies	6.55
22	Harrison Poultry, Inc.	5.54
23	Allen Harim Foods, LLC	5.20
24	Golden-Rod Broilers, Inc.	3.12
25	Farmers Pride, Inc.	2.79
26	Holmes Foods	2.20
27	Miller Poultry	1.67
28	Gerber's Poultry	1.50
29	MBA Poultry, LLC	1.25
30	Gentry Poultry Co., Inc.	1.00
31	Hain Pure Protein Corp.	0.95
32	Murray's Chickens/MB Food Processing Inc.	0.83
33	Empire Kosher Poultry, Inc.	0.83
34	Agri Star Meat & Poultry, LLC	0.27
35	Eberly Poultry, Inc.	0.08
	TOTALS	789.51

Figure 5.51: Million Lb. of Broiler Production for the Top 35 Companies in 2013 Per Week

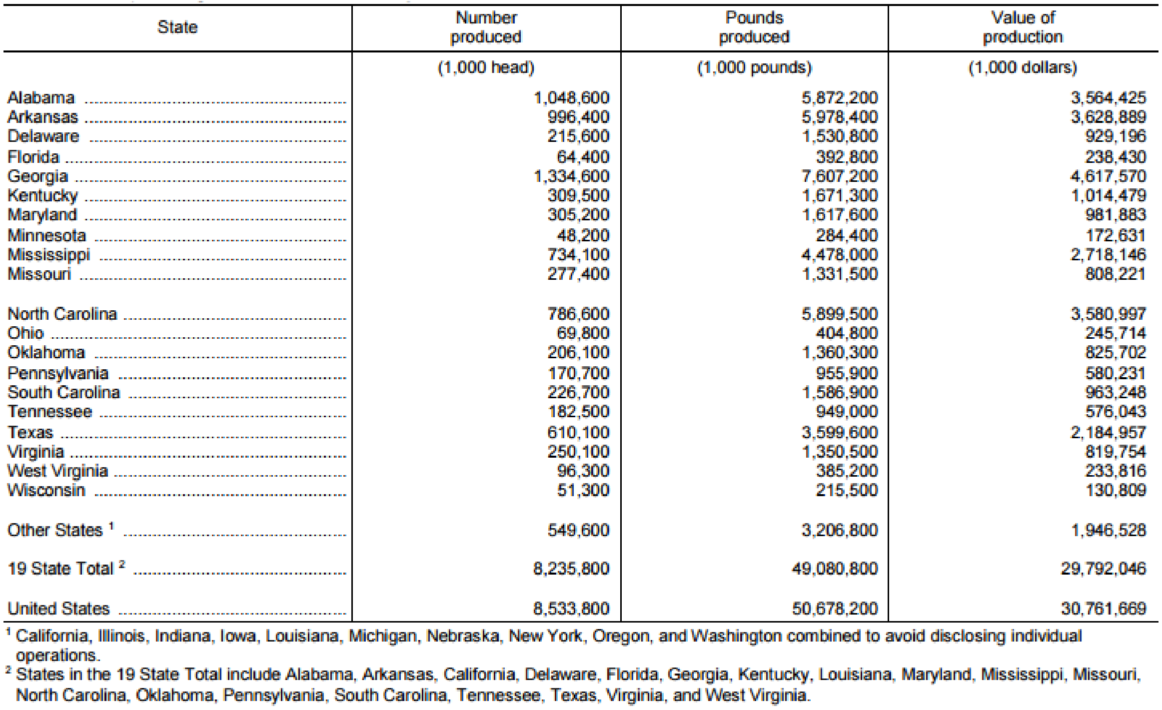
Originally, this information was to be used with Form 10-K from the US Securities and Exchange Commission for each of these 35 companies to determine how many facilities each company has, and if possible, locate these facilities. Knowing the location and production of these facilities would be vital in order to create specific points of "production" necessary in creating and OD Matrix. In addition, Form 10-K provides information with regards to revenue (although the revenue is generally aggregated for the whole company and so it may not differentiate between different sources of revenue).

Unfortunately, this approach did not work for two reasons. First, many of the companies listed in Figure 5.51 are not publicly traded and thus Form 10-K is not available for them. Second, even in the event that a company is publicly traded, most of the time their Form 10-K may provide the total amount of facilities of each type owned, as in Figure 5.51, but it will not provide their specific location. Thus, this approach would require the research team to manually find information about the location and production of each of the processing facilities owned by each of the 35 broiler companies. Though this benefit of this approach is high (knowing the exact location and production value of each of the "productions" required to perform a gravity model). it also has a high cost. For this reason, the research team decided to keep everything aggregated at the "state" level by using USDA poultry production information. For Texas, however, the main processing plants (11 of them) actually were located, using a combination of Socrates, personal communication with company employees willing to engage with the research team, and company websites if they provided information about the location of their facilities.

Nonetheless, the WATT Poultry Report data is still important in order to validate information from the USDA. In fact, using information from the USDA, the research team originally assumed that the US broiler production in 2013 was 50.7 billion lbs. However, the WATT Poultry Report gives a much lower number. It was only because of this discrepancy that the research team examined this value further until it was discovered that the reported 50.7 billion lbs. are actually a "live weight" of broilers. Thus, in order to find what the weight was after production, it was assumed that post-production weight is 75% of live weight, yielding 38.0 billion lbs. of production in 2013.

USDA State Production Data

Due to the decision to keep all broiler production data aggregated at the state level for all states other than Texas, the USDA data proved to be one of the two most important data sets used. The values reported by the USDA for the year 2013 are shown in Figure 5.52. In 2013, Texas produced 610 million broilers, which is equivalent to 3,600 million pounds of live weight (5.90 lb. per broiler).



State	Number produced	Pounds produced	Value of production
	(1,000 head)	(1,000 pounds)	(1,000 dollars)
Alabama	1,048,600	5,872,200	3,564,425
Arkansas	996,400	5,978,400	3,628,889
Delaware	215,600	1,530,800	929,196
Florida	64,400	392,800	238,430
Georgia	1,334,600	7,607,200	4,617,570
Kentucky	309,500	1,671,300	1,014,479
Maryland	305,200	1,617,600	981,883
Minnesota	48,200	284,400	172,631
Mississippi	734,100	4,478,000	2,718,146
Missouri	277,400	1,331,500	808,221
North Carolina	786,600	5,899,500	3,580,997
Ohio	69,800	404,800	245,714
Oklahoma	206,100	1,360,300	825,702
Pennsylvania	170,700	955,900	580,231
South Carolina	226,700	1,586,900	963,248
Tennessee	182,500	949,000	576,043
Texas	610,100	3,599,600	2,184,957
Virginia	250,100	1,350,500	819,754
West Virginia	96,300	385,200	233,816
Wisconsin	51,300	215,500	130,809
Other States [1]	549,600	3,206,800	1,946,528
19 State Total [2]	8,235,800	49,080,800	29,792,046
United States	8,533,800	50,678,200	30,761,669

[1] California, Illinois, Indiana, Iowa, Louisiana, Michigan, Nebraska, New York, Oregon, and Washington combined to avoid disclosing individual operations.

[2] States in the 19 State Total include Alabama, Arkansas, California, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, and West Virginia.

Figure 5.52: Broiler Production by State in 2013[10]

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[10] The weight reported is the live weight

One particular fact that validates the data found so far is the following: in Texas, a total of 11 broiler processing plants have been found. Personal communication with a representative at Holmes Foods, revealed that 10 of these 11 plants have a capacity of about 1.2 million broilers per week and are used at about 90% capacity. The 11th processing facility, operated by Holmes Foods, has a capacity of 750,000 broilers per week and is most often used at very close to full capacity. By taking the weekly production of these 11 processing facilities and converting to an annual production, it is estimated that in 2013 Texas produced 3,682 million pounds. This value is within 3% of the value reported by the USDA.

The main drawback of using data aggregated to the state level is the fact that it will make the routing part of this project much more difficult. Depending on where in a neighboring state the production is occurring, it will make a huge difference what roads are being used to deliver the product. For example, if broilers are processed in Louisiana, then we need to know what part of Louisiana they are coming from in order to predict what roads will be used. One suggestion to overcome this issue is to assume that all broilers are processed at the geographic centroid of each state and to assume that most of the error in routing will be cancelled out by other states and their routes. This assumption is acceptable as the focus of this study is the intrastate travel within Texas.

USA Trade Data

Along with the USDA State Production Data, the other most vital data source used is the USA Trade Data, which provides import and export data by port and by commodity type. The information provided is in dollars and shipping weight (in kg). Because shipping weight includes the weight of anything used to transport the commodity (except for the container itself) and thus is not a useful attribute, the research team had to assume a cost per pound of $0.61; this is the same value used for domestic production.

The sum of all broiler exports in 2013 was $4.6 billion or 7.6 billion lbs. using a conversion of $0.61/lbs. If, as mentioned earlier, the US produced a total of 38.0 billion lbs. of broilers then this implies that about 19.9% of all production was exported. This is very close to 19.6%, the number reported by the National Chicken Council (2016) for 2013.

While the amount of broiler products exported was high, the amount of broiler products imported was much lower (~$166M or 274 million lbs.). The types of chicken products that the research team took into account are the following:

- Live chickens (categorized as above and below 185 grams each), ~ 5% of exports by value
- Meat & offal of chickens that is not cut and is fresh or chilled, <1% of exports by value
- Meat & offal of chickens that is not cut and is frozen, ~ 1% of exports by value
- Chicken cuts & edible offal (including liver) that is fresh or chilled, 11% of exports by value
- Chicken cuts & edible offal (including liver) that is frozen, ~83% of exports by value
- Poultry fat, that is not rendered, <1% of exports by value

5.3.4 Commodity Flow Estimation

Working with the production data by state (from the USDA) and export and import data by state (from USA Trade), it is possible to estimate how many pounds of broilers are available for each American per year using Equation (5.1). The value reported by Equation 5.1—97.2 lbs. per capita—is not representative of how much broiler meat an average American actually eats each year, as it is the weight of the carcass. When accounting for the amount of boneless meat, this value gets reduced by about 40% (Bentley, 2015) to 57.8 lbs. of available broiler meat per capita. This is very close to the number reported by the US Poultry & Egg Association (2016) of 57.4 lbs. of broiler meat per capita. Also, about 86% of the carcass weight (Bentley, 2015) (about 82.8 lbs. per capita) makes it to market for human food while the rest is either used for dog food or is thrown out for various reasons (e.g., meat defects).

$$\frac{Broiler\ Consumption}{Capita} = \frac{Domestic\ Broiler\ Production + Broiler\ Imports - Broiler\ Exports}{US\ Population} \approx \frac{38.0\ billion\ lbs. + 0.3\ billion\ lbs. - 7.6\ billion\ lbs.}{0.316\ billion\ people} \approx \frac{97.2\ lbs.}{capita} \tag{5.1}$$

In order to calculate the demand of each state, Equation 5.2 is used. In order to calculate the supply of each state, Equation 5.3 is used. Table 5.8 shows the supply, demand, and surplus/deficit of each

$$State\ Demand = \frac{97.2\ lbs.}{capita} * State\ Population + State\ International\ Exports \tag{5.2}$$

$$State\ Supply = State\ Production + State\ International\ Imports \tag{5.3}$$

Table 5.8: Demand and supply by US state

Region or State	Total Demand 2013 (M lb)	Total Supply 2013 (M lb)	Net Supply 2013 (M lb) (+ = surplus, - = deficit)
United States	38,282	38,282	-
Alabama	1,119	4,404	3,285
Alaska	72	-	(72)
Arizona	687	0	(687)
Arkansas	288	4,484	4,196
California	4,278	962	(3,317)
Colorado	512	-	(512)
Connecticut	349	-	(349)
Delaware	90	1,148	1,058
District of Columbia	68	-	(68)
Florida	2,485	311	(2,174)
Georgia	3,012	5,710	2,699
Hawaii	138	0	(138)
Idaho	159	-	(159)
Illinois	1,271	65	(1,206)

Region or State	Total Demand 2013 (M lb)	Total Supply 2013 (M lb)	Net Supply 2013 (M lb) (+ = surplus, - = deficit)
Indiana	638	65	(573)
Iowa	300	65	(235)
Kansas	281	-	(281)
Kentucky	427	1,253	826
Louisiana	1,095	943	(153)
Maine	133	0	(133)
Maryland	630	1,213	584
Massachusetts	650	-	(650)
Michigan	1,525	210	(1,315)
Minnesota	527	213	(313)
Mississippi	291	3,359	3,068
Missouri	587	999	411
Montana	104	0	(104)
Nebraska	182	65	(117)
Nevada	271	-	(271)
New Hampshire	129	-	(129)
New Jersey	865	-	(865)
New Mexico	203	-	(203)
New York	2,120	124	(1,996)
North Carolina	1,083	4,425	3,342
North Dakota	78	0	(77)
Ohio	1,139	304	(835)
Oklahoma	374	1,020	646
Oregon	382	65	(317)
Pennsylvania	1,254	731	(523)
Rhode Island	102	-	(102)
South Carolina	758	1,190	432
South Dakota	82	-	(82)
Tennessee	631	712	81
Texas	3,873	2,701	(1,172)
Utah	282	-	(282)
Vermont	61	4	(57)
Virginia	1,124	1,013	(111)
Washington	780	76	(705)
West Virginia	180	289	109
Wisconsin	558	162	(396)
Wyoming	57	-	(57)

Using the supply and demand for broilers for each state, it is possible to develop a state-to-state OD Matrix using a gravity model, where the impedance is based on the distances between each state's most populous cities. Table 5.9 shows the top five states that Texas exports to and the top five states that Texas imports from. From this same gravity model, it is predicted that 1,157 M lbs of broilers start (either at Texas production facility or an international port) and end (either in a Texas county for local consumption or at an international port) in Texas.

Table 5.9: Top five states that Texas exports to and imports from

Exports out of Texas (M lb)		Imports into Texas (M lb)	
Total	1,543.3	Total	2,713.0
California	308.6	Arkansas	578.0
Florida	93.5	Mississippi	470.5
Louisiana	82.9	Alabama	348.3
Georgia	71.5	Georgia	341.3
Arizona	62.1	North Carolina	207.0

Next, the research team focused on finding the OD Matrix of chicken products within Texas. In order to do this, the production and consumption of each zone is required. Production zones are the following:

1. The 11 broiler processing facilities in Texas
2. Three international ports in Texas
3. Interstate border points that are used in the chicken product supply chain

The exact amount for items 1 and 2 is known. However, the amount for item 3 is not known because information is not available on the interstate border points used in broiler transport.

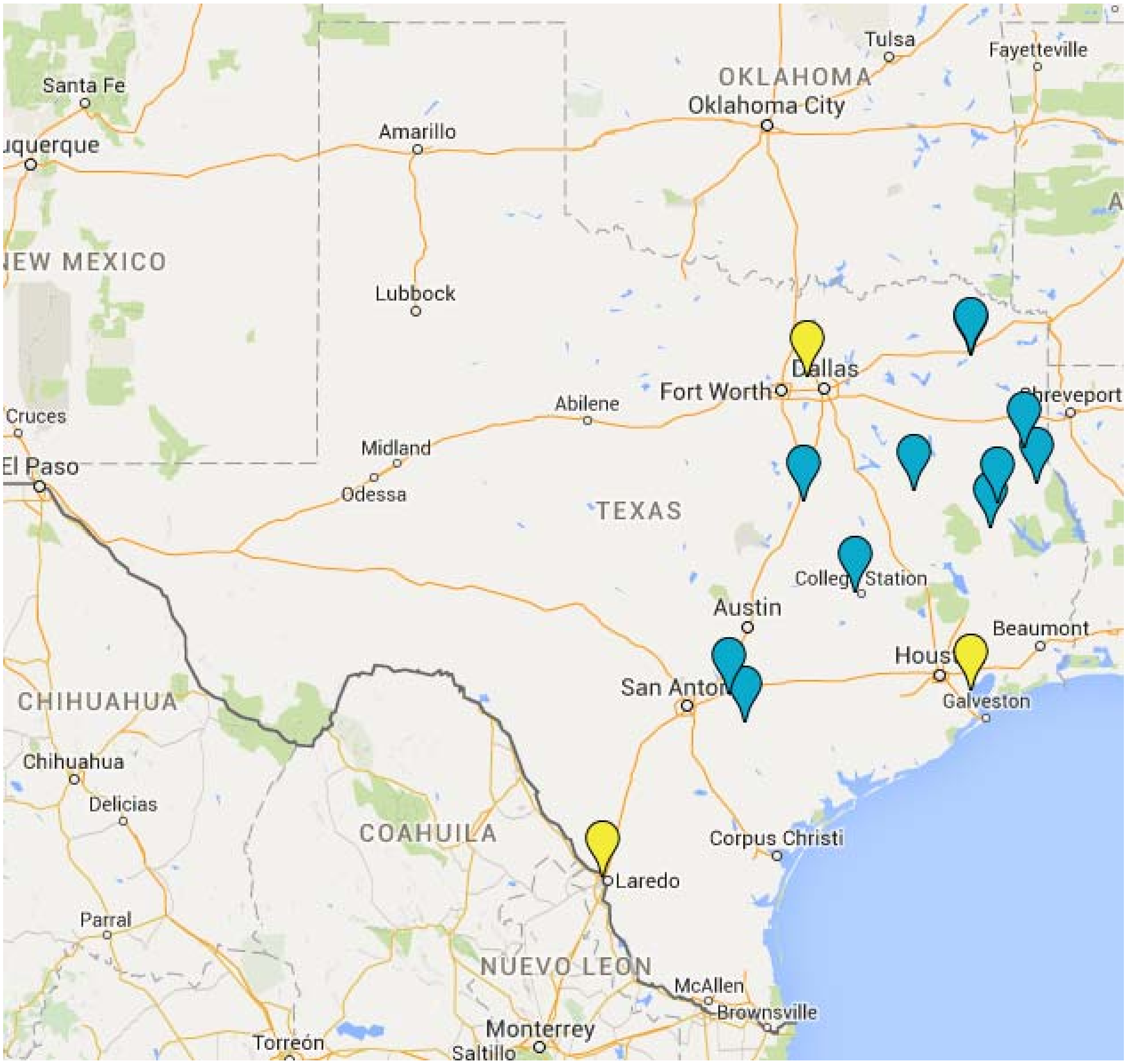
Consumption zones are the following:

1. Each of the 254 counties with a known population. The demand for each county is the product of the county's population and consumption per capita from Equation (5.1)
2. 14 International ports in Texas
3. Intrastate border points that are used in the chicken product supply chain

As before, the exact amount of items 1 and 2 is known, but the amount for item 3 remains elusive, since it is not known what interstate border points are used to transport the broilers. To resolve the issue of not knowing the interstate border point, the research team decided to, for now, only model an internal-internal OD Matrix while the imports and exports from other states will be taken care of in a later task during the assignment stage. Thus, in the internal-internal OD Matrix, the research team considers the international imports and exports as well as the Texas production that is staying within Texas but imports and exports to other states are not considered.

This approach requires one key assumption. As shown by Equation (5.1), the per capita broiler demand is about 97 lbs. However, the internal flow within Texas (1,157 M lbs.) cannot even fully satisfy the demand that is going to international ports for exporting abroad (1,304 M lbs); the full demand can only be satisfied when imports from all other states (2,713 M lbs) are also considered. Thus, the main assumption is that in order to model how the 1,157 M lbs. can dispersed through Texas, each region's demand will be 30% of its actual demand (since 1,157/(1,157 + 2,713) = 0.3) while the other 70% will be satisfied in a later model that incorporates imports from other states. Using the same logic, it is assumed that production in Texas is reduced by 43% (including what is brought in via international ports), while the other 57% will be used to satisfy the demand for other states in a later model.

Using this approach, there are a total of 13 counties where broilers may originate. These 13 counties include 10 counties where broilers are being processed and three counties where broilers are being imported from out of the country. Thus, the County-to-County OD Matrix that is 254 x 254 for Texas will actually only have 13 rows since all the other rows will be zero. These 13 origin points are shown in Figure 5.53. Blue markers represent processing locations while the yellow markers represent international ports where broiler products are imported from another country.



(Blue markers = processing locations; yellow markers = international ports where broiler products are imported from another country).

Figure 5.53: Counties in Texas That Are the Sources of Broiler Products

These ten counties process broilers in Texas:

- Anderson County
- Angelina County
- Brazos County
- Gonzales County
- Guadalupe County
- McLennan County
- Nacogdoches County
- Panola County
- Shelby County
- Titus County

It is worth noting that since the US produces substantially more broilers than it consumes, the supply from imports is miniscule compared to domestic production. In fact, according to conversion factors, the research team estimates that in 2013 Dallas County imported around 9,000 lbs. of broiler products. Dispersed among 254 counties, the gravity model will allocate just a few pounds to some counties. This is not what occurs in reality; the way to fix this is to set a minimum threshold on the amount of product that may be shipped from an origin to a destination and if this threshold is not surpassed, then the amount shipped is automatically set to zero. However, because the amounts being shipped are so low, making this correction is not particularly problematic, since it does not impact the industry as a whole. These three counties import broiler products in Texas:

- Dallas County
- Harris County
- Webb County

The county-to-county OD matrix produced based on the procedure described in previous sections had quite a few counties where the demand was very low due to the population in the county also being low. Indeed, there were many cells in the OD matrix that were much lower than 20,000 lbs; this means that for these counties, just one Class 6 truck would be able to deliver the demand for the entire year! However, it is not probable that a broiler company sends one truck annually to a sparsely populated county in, for example, west Texas, and does not travel to the county again until the same time next year.

Instead, the research team found that, as of 2000, there were 65 sparsely populated counties where 100% of the population did not have access within 10 miles to even one grocery store with at least 50 employees. In addition, there were another 39 counties where at least 50% of the population did not have access within 10 miles (Morton & Blanchard, 2007). Since 2000, many rural communities have gotten even smaller due to the effect of urbanization; thus, it can only be expected that the number of these counties where grocery stores are rarely, if at all, available has increased. For this reason, the research team adjusted the demand by assuming broiler products do not get delivered to these 104 counties (65 counties and 39 counties). Instead, the demand for them is passed off to the closest county that is not on this list of 104 counties (i.e., more than 50% of the population has access to at least one grocery store within 10 miles). This allowed for the elimination of many cells in the original OD matrix that had just a few hundred pounds. The 104 counties that had their demand passed to another county are shown in dark green in Figure 5.54.

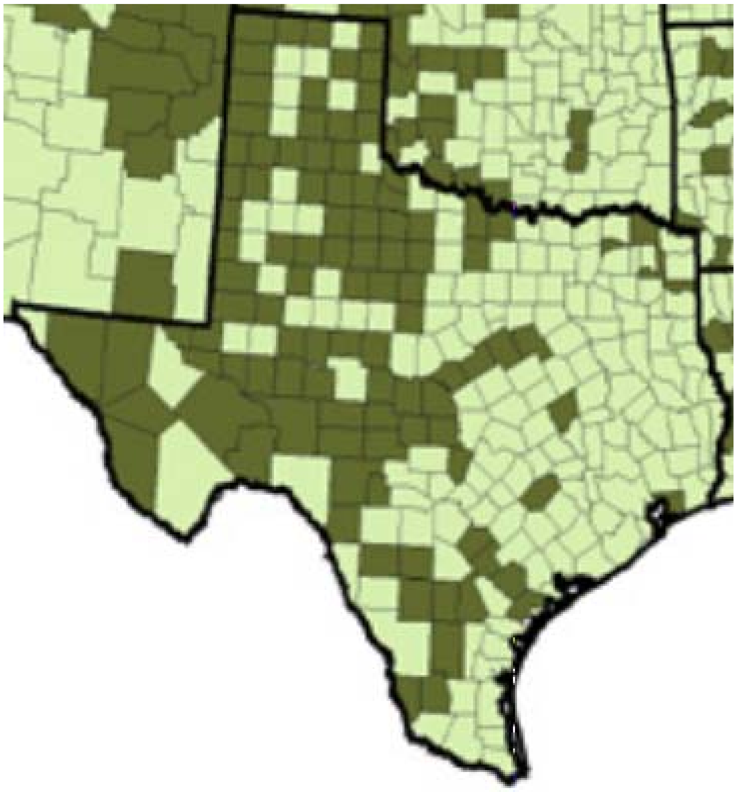


Figure 5.54: Counties in Texas where 50% or More of the Population Did Not Have Access within 10 Miles to a Grocery Store Employing at Least 50 People (Dark Green), as of 2000

Another adjustment was made for broiler products that are imported from abroad. The amount of broilers imported into the US, and especially Texas, is very low. Indeed, there are only three counties (Dallas, Harris, and Webb) that imported broiler products in 2013 and even these three counties did not import much. Thus, rather than using a gravity model to disperse imports throughout the state, an assumption was made that all imports will stay inside the importing county. For example, this means that the roughly 9,000 lbs of broiler product imported into Dallas in 2013 was modeled to remain in Dallas. Given how small the amount imported is, even if this assumption is not entirely true, it will not affect the results of the model.

5.3.5 Transportation

Truck Type

The truck most often used for transporting processed broiler meat from processing plants to market, which includes retail, distributors, wholesalers, etc., is the Class 9 single trailer five-axle truck, as shown in Figure 5.55. A representative from the US Poultry & Egg Association estimates that this truck is used about 95% of the time. In the other 5% of the cases, he estimates that a Class 6 single unit three-axle truck, shown in Figure 5.56, is used most often.

Figure 5.55: Class 9 Single Trailer Five-axle Truck Most Commonly Used to Transport Processed Broiler Meat (FHWA)

Figure 5.56: Class 6 Single Unit Three-axle Truck Sometimes Used to Transport Broiler Meat (FHWA)

In our modeling, the research team assumed that Class 6 trucks are never used for interstate shipping of broilers. This is because interstate shipping implies long-distance travel where the profit margins are very small, and thus most broiler companies would have to ship large volumes in order to financially justify the journey.

Therefore, for analysis of state-to-state shipping, the research team assumed that only Class 9 single trailer five-axle trucks are used. For intrastate shipping in Texas, the research team assumed that both Class 9 and Class 6 are used, with Class 9 trucks being much more common. This approach is confirmed by the fact that most pictures of broiler company trucks found online are indeed Class 9. An example of such a truck is shown in Figure 5.57. If the research team discovers during future research that, for example, the market is shifting toward new truck classes (with new allowable weight limits), the Excel-based models the research team developed can be updated by simply changing the weight that the trucks are carrying.

Figure 5.57: Typical Truck (Class 9 by the FHWA Standards) Used by Broiler Companies

Truck Capacity

According to the same US Poultry & Egg Association representative mentioned earlier, Class 6 trucks usually have a GVW of around 40,000 lbs. Approximately half of this weight is the tare weight while the other half, 20,000 lbs, is broiler meat. Also, Class 9 trucks usually have a GVW of around 80,000 lbs. Again, half of this is tare weight while the other 40,000 lbs are broiler meat.

However, this does not have to hold true for all stages of the broiler supply chain. For example, a Tyson Foods live haul manager (live haul is the part of the supply chain that goes from the farm to the processing plant) stated that each trailer gets only about 32,000 lbs of broiler chickens, even though they are still using a Class 9 truck. Nonetheless, since the research team modeled only the part of the supply chain from processing plants to market, cargo weights of 20,000 and 40,000 lbs for Class 6 and Class 9 trucks, respectively, are used.

Converting Tonnage to Equivalent Trucks

The research team found the number of equivalent truck trips in the following way:

- For state-to-state shipping, it was assumed that each truck carried 40,000 lbs of broiler product.
- For county-to-county shipping:
    - If the total amount being shipped from one county to another was less than 40,000 lbs, then it is assumed that all product is shipped via one or two Class 6 trucks that can each carry up to 20,000 lbs.
    - If the total amount being shipped from one county to another was greater than 40,000 lbs, then it is assumed that 99.5% of the total weight is assigned to Class 9 trucks that carry an average of 40,000 lbs. Class 6 trucks, with a capacity of 20,000 lbs, are used to transport 0.5% of the total weight.
    - Previous steps result in Class 6 trucks being used roughly 6% of the time, which is close to the 5% previously mentioned in the "Truck Type" section.

Estimating Empty Trucks

In the case of state-to-state shipping, it is assumed that 0% of the trucks return empty. There are three reasons for this assumption:

- Shipping from one state to another can yield low profit margins and companies are less likely to ship to another state if trucks must return empty, as that will mean even higher inefficiencies.
- Big companies that are likely to ship into Texas, such as Pilgrim's Pride and Tyson Foods, Inc., have their own truck fleet. They also have plants in Texas. Thus, rather than returning empty, they are more likely to head to a plant in Texas for another load. The main exception to this is Perdue Farms, as they do not have plants in Texas.
- Small companies that may ship to Texas do not own fleets. Instead, they must contract with common carriers. In order to stay profitable, common carriers do their best to minimize the amount of empty truck trips.

In the case of county-to-county shipping, it is assumed that only counties that have processing plants operated by Pilgrim's Pride and Tyson Foods, Inc. will have empty truck trips. This is because Pilgrim's Pride and Tyson Foods, Inc. both have their own fleet. Such companies, as mentioned by the US Poultry & Egg Association representative, will generally return to their own plants to be cleaned before taking another load. The possibility that their truck could return empty to another one of their plants, rather than the one at which they started, was not considered.

In the case of the other broiler companies in Texas, namely Holmes Foods, Inc. and Sanderson Farms, it is assumed that their trucks do not return empty because they work with common carriers that prevent this. The research team could not obtain full confirmation that Sanderson Farms does not indeed have their own truck fleet; for this reason, the model can be easily updated if it is discovered that return trips associated with Sanderson Farms are supposed to be empty.

Results

Full results, showing the number of truck trips from county to county and state to state, are included in Appendix 1 of this report. Tables 5.10 and 5.11 provide a brief summary for Texas.

Table 5.10: Total number of loaded Class 9 trucks for the top five states that trade with Texas modeled for 2013 that travel (a) to Texas and (b) from Texas, rounded to the nearest hundred

Arkansas	14,500
Mississippi	11,800
Alabama	8,700
Georgia	8,500
North Carolina	5,200

(a)

California	7,700
Florida	2,330
Louisiana	2,100
Georgia	1,800
Arizona	1,600

(b)

Table 5.11: Total number of loaded trucks (irrespective of class) modeled for 2013 that travel between the origin (rows) and the top five destinations[11] in Texas (columns)

	Webb County	Harris County	El Paso County	Dallas County	Bexar County
Anderson County	468	501	186	231	163
Angelina County	482	683	181	142	110
Brazos County	488	681	156	117	97
Dallas County	-	-	-	1	-
Gonzales County	510	286	109	48	43
Guadalupe County	728	320	153	64	59
Harris County	-	5	-	-	-
McLennan County	487	373	185	211	193
Nacogdoches County	491	600	193	165	124
Panola County	502	520	212	183	137
Shelby County	510	578	207	163	124
Titus County	946	775	448	503	353
Webb County	9	-	-	-	-
Total	**5,621**	**5,322**	**2,030**	**1,828**	**1,403**

5.3.6 Network Analysis

The truck trips for the transport of broilers from processing plants to retail wholesale estimated in the previous section are assigned to the created freight network following the procedure described in Section 4.3. Results are represented in Figure 5.58 (Class 6 truck), Figure 5.59 (Class 9 truck), and Figure 5.60 (total).

Figure 5.58 indicates that Class 6 broiler truck trips are mostly concentrated in between the big cities (Austin, San Antonio, Houston, and Dallas-Fort Worth), which is as expected since Class 6 trucks are mainly used for short-distance transport. IH 35 between San Antonio and Dallas-Fort Worth carries the highest number of Class 6 broiler trucks (about 300 trucks annually), followed by US 59 between Houston and Lufkin, IH 20 between Fort Worth and Longview, IH 30 between Dallas and Mt Pleasant, and IH 10 between San Antonio and Houston. However, as most boilers are transported by Class 9 trucks, the number of Class 6 Broiler trucks on the network is not high.

As stated in previous section, the majority of interstate broiler transportation and all state-to-state broiler transportation uses Class 9 trucks. Most broilers imported into Texas are coming from Arkansas, Mississippi, and Alabama via IH 30 and IH 20. Some sections of these two highways carry more than 30,000 Class 9 broiler trucks annually. Most of broilers exported from Texas are going to Louisiana from Houston via IH 10. Annual broiler Class 9 truck trips on this section of IH 10 total more than 20,000 annually. As Class 9 trucks are the majority, so the network

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[11] These five counties make up just over 50% of all the truck trips modeled for Texas.

pattern of total truck trips is very similar to that of Class 9 trucks, except that the number of trucks will be slightly higher. See Figures 5.59 and 5.60.

The value of broiler used in the network analysis is 40¢ per lb. This value was estimated using the USDA's *Broiler Market News Report* published on November 4, 2016 (USDA, 2016). Based on this value, a Class 9 truck with 40,000-lb capacity can carry broiler shipments worth $16,000 and a Class 6 truck with 20,000-lb capacity can carry broiler shipments worth $8,000.

The estimated value (in thousands) of broiler movements on the freight network is displayed in Figure 5.61. The movements of broilers on IH 30 between Dallas and Kansas, IH20 between Dallas and Mississippi, IH 10 between Houston and Louisiana, and a section of IH 35 between Austin and Dallas are worth more than $2.25 million annually. IH 35 between Dallas and Oklahoma City, IH 35 between San Antonio and Austin, IH 10 between San Antonio, and US 59 between Houston and Shreveport all carry broiler movements worth more than $1.5 million annually.

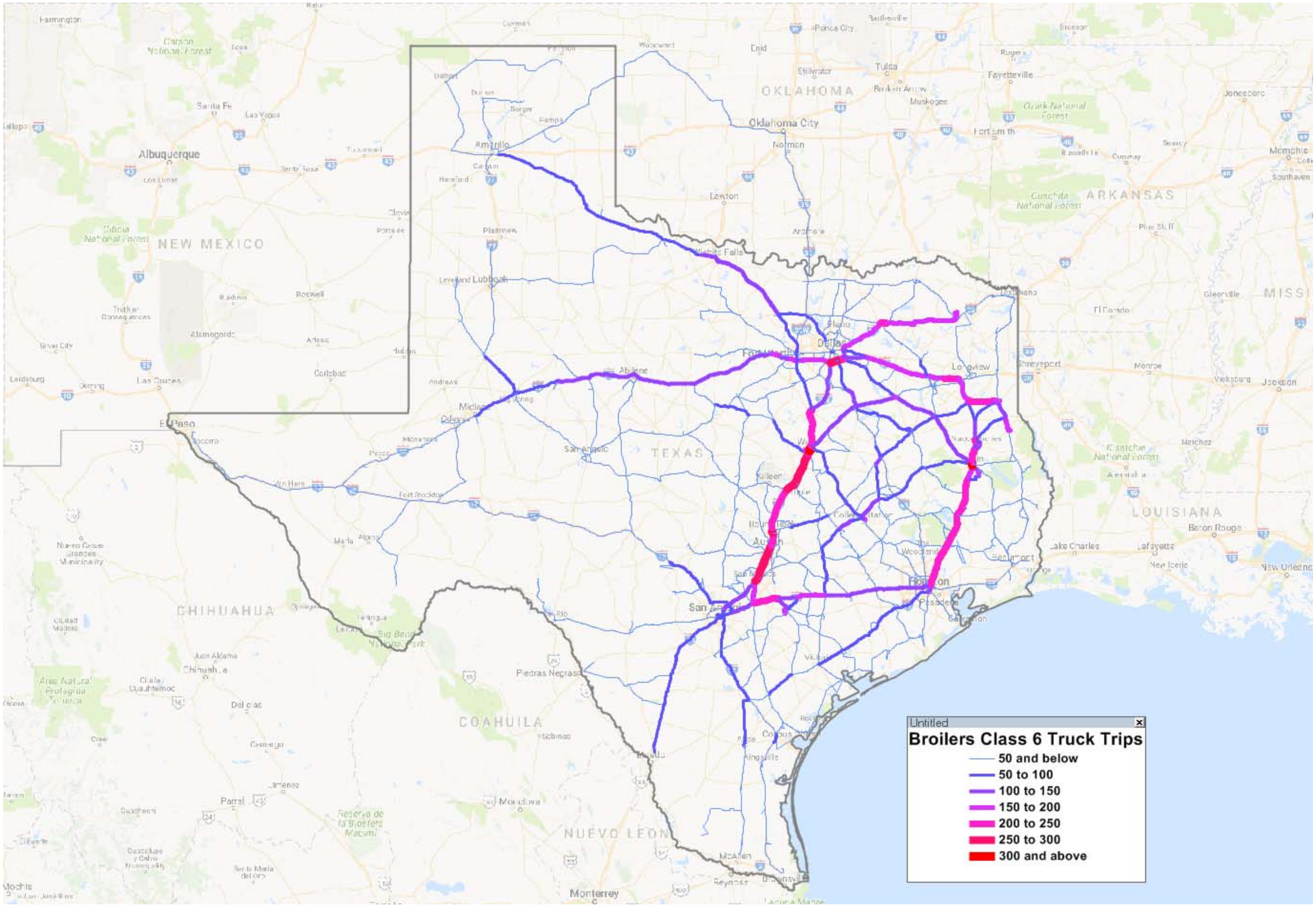


Figure 5.58: Broilers Class 6 Truck Trips

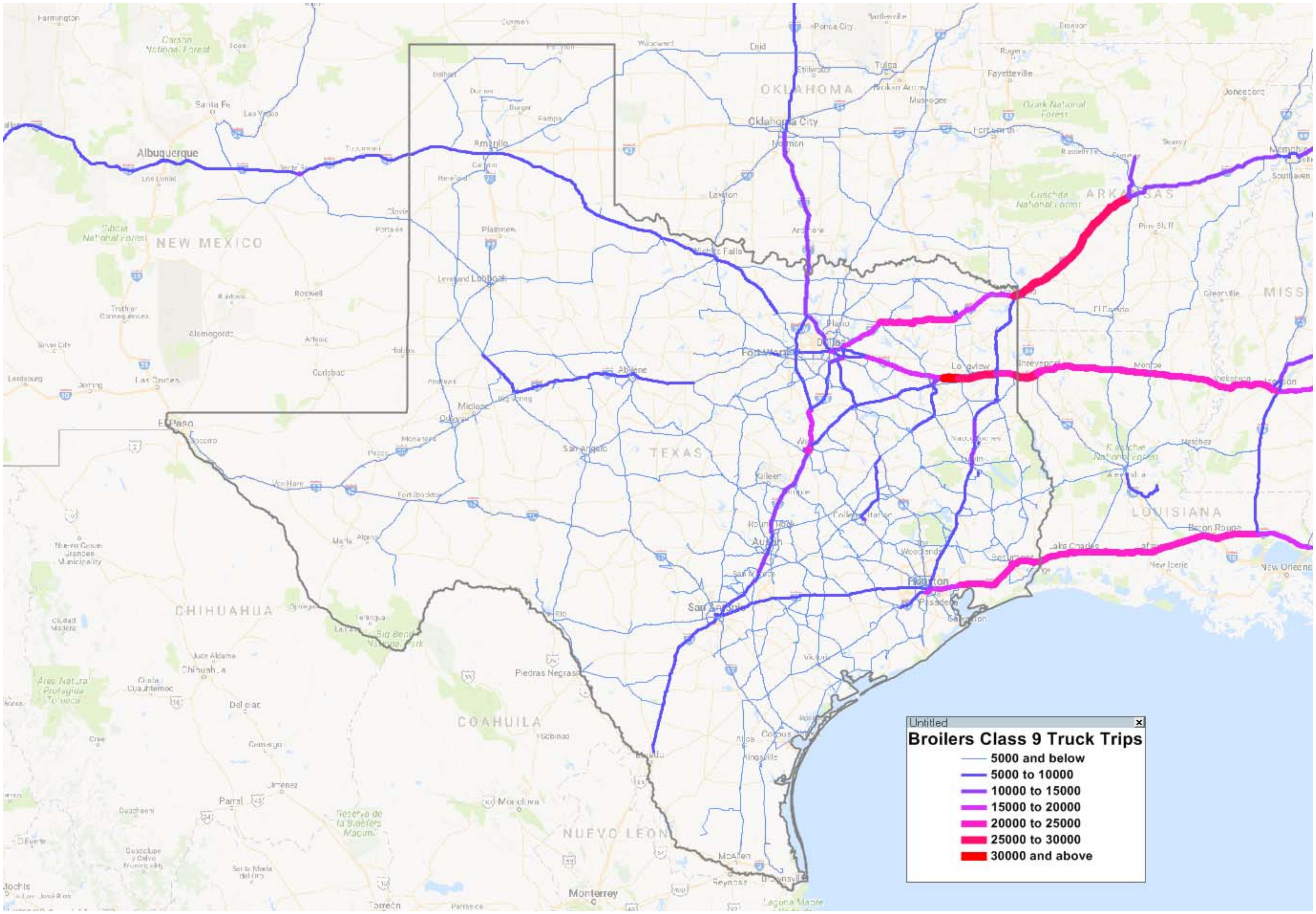


Figure 5.59: Broilers Class 9 Truck Trips

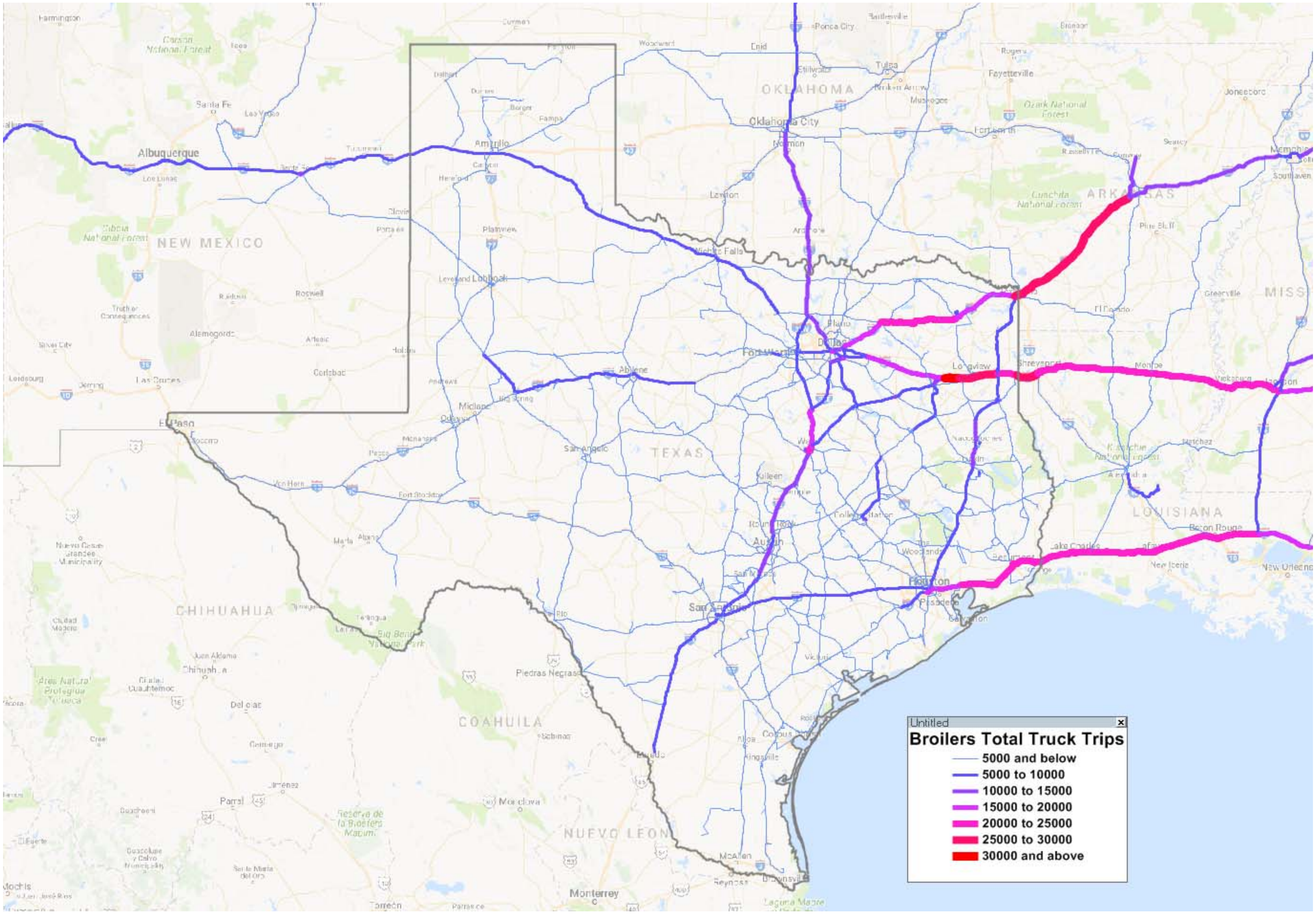


Figure 5.60: Broilers Total Truck Trips

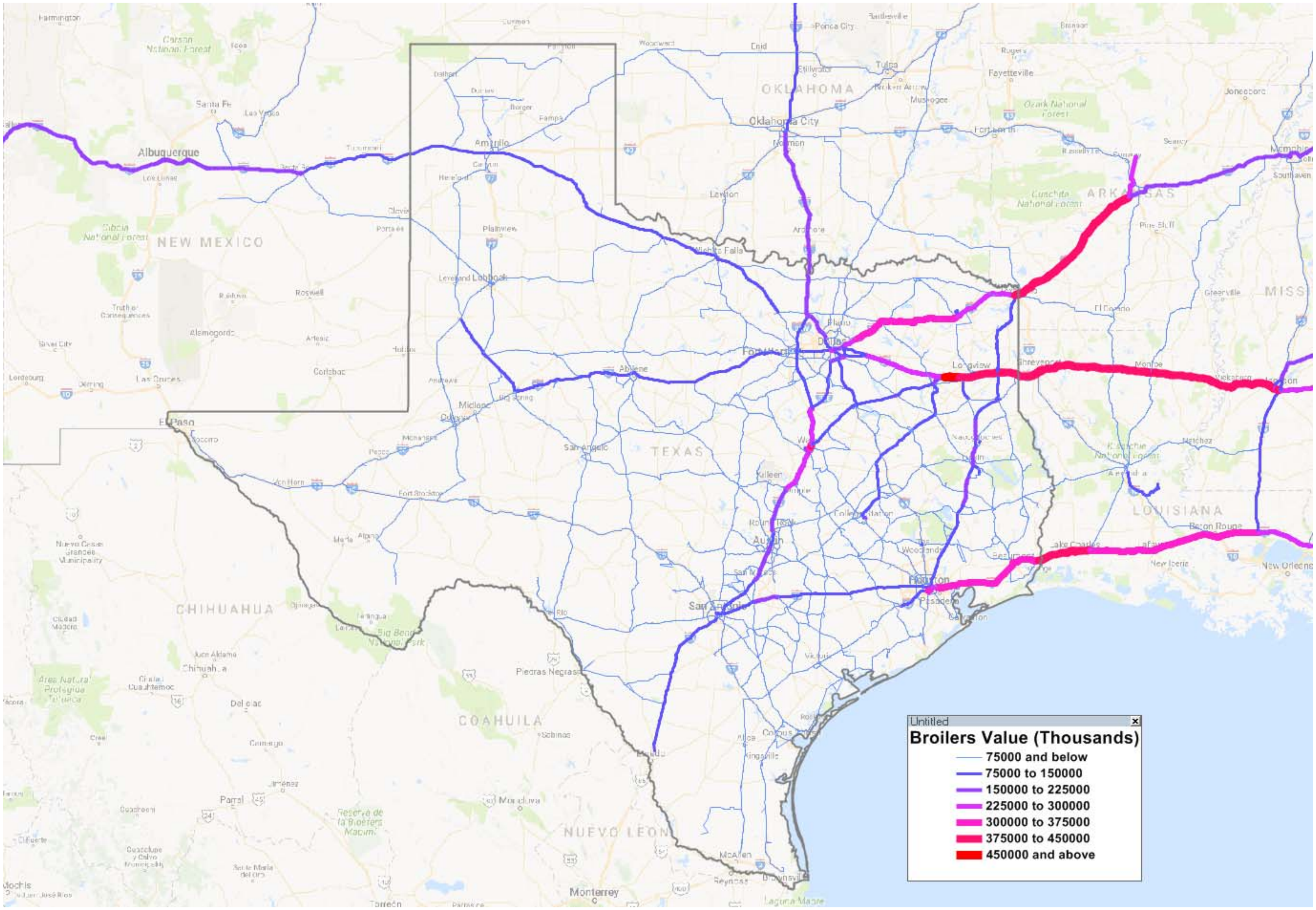


Figure 5.61: Broilers Value

5.3.7 Compare with Transearch Data

As shown in Table 4.1, the closest commodity category to broilers in the Transearch database is frozen dressed poultry (STCC 20 16). The research team processed the frozen dressed poultry data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.62.

The Transearch data indicates large frozen dressed poultry flows from Arkansas to California, which pass through the Texas panhandle. These flows overshadow the flows everywhere else within the state. The broilers estimated in this projects include not only frozen dressed poultry, but also other types of chicken and chicken products, such as chicken wings or chicken nuggets and even dog food products (products that underwent secondary processing); therefore, the flow patterns derived from Transearch data (Figure 5.62) and that estimated by the research team in this project (Figure 5.60) are quite different. Due to the different products included in those commodity categories, it is hard to make a fair direct comparison between these two estimates.

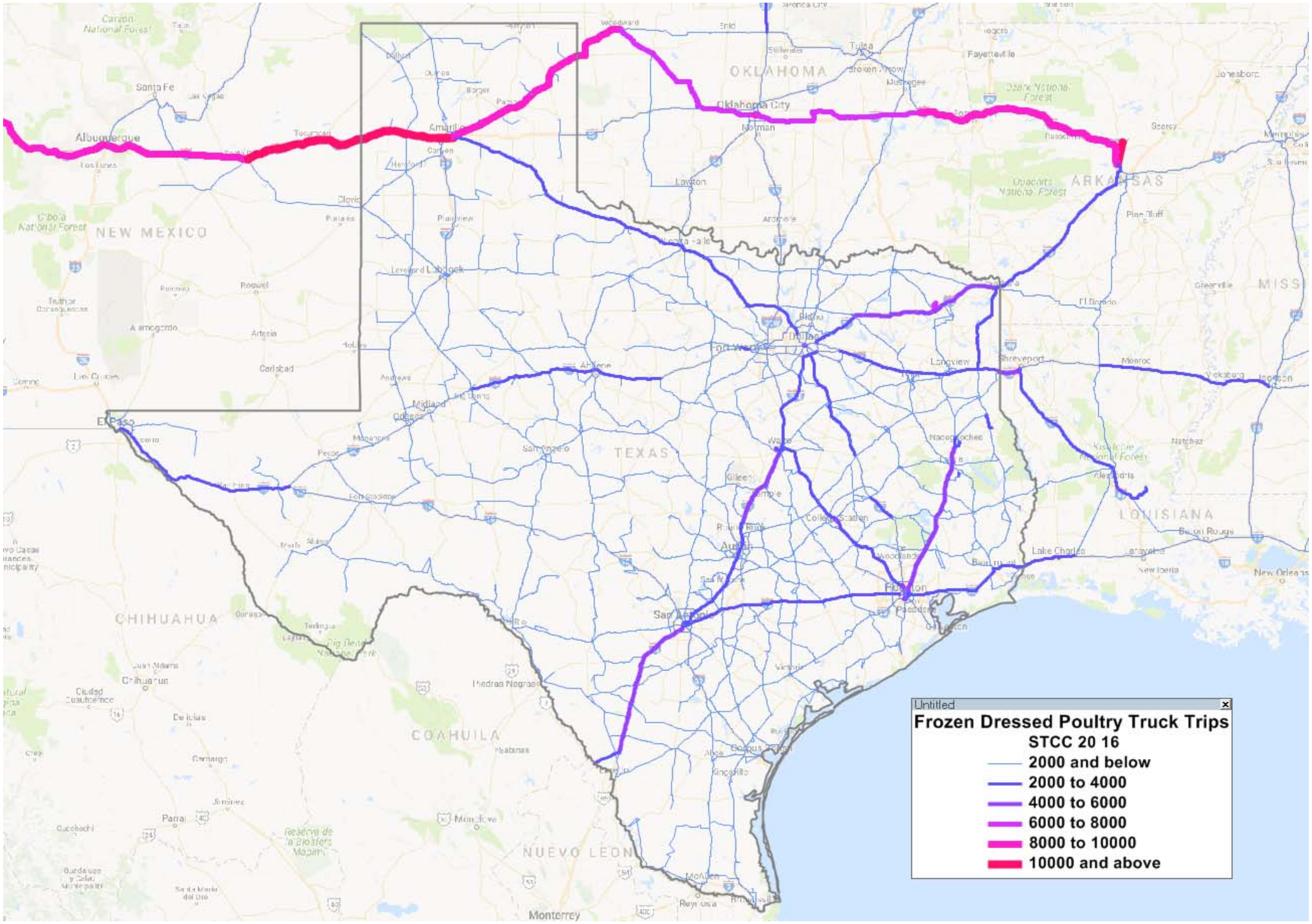


Figure 5.62: Transearch Frozen Dressed Poultry Truck Trips

5.3.8 Seasonal Variation

The monthly number of broilers for meat production is collected from broilers reports on the USDA website. Then, the percentage of production for each month is calculated. The proportion of chicken for each month is in the range of 8 percent to 8.5 percent (USDA, 2017). The monthly percentage of number of broilers slaughtered for meat production is shown in Figure 5.63. Based on the graph, the correlation between broilers and eggs and the hypothesis test (with $X^2 = 2.21 < X_t^2 = 5.58$), it is concluded that there is no noticeable seasonal variation for broilers' movement in Texas.

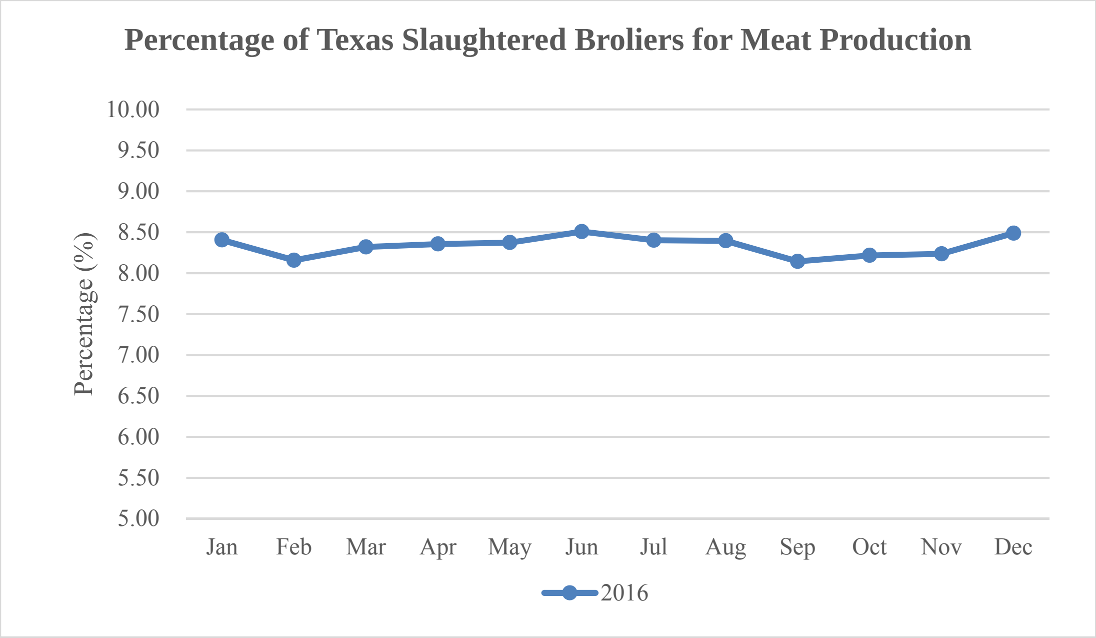


Figure 5.63: Run Sequence Plot of Monthly Percentage of Slaughtered Broilers for Meat Production in Texas

5.3.9 Daily Truck Trip Assignment

Since no significant seasonal variation was observed on broilers' movement, it was assumed that the number of daily truck trips are the same for every month. In this case, as described in Section 4.5.3, the daily truck trip matrix was obtained by dividing the annual truck trip matrices by 295, the factor used in SAM to convert daily trips to annual trips. The daily truck trips were then assigned to the network with the impact of congestion taken into consideration.

The new traffic assignment results shown in Figure 5.64 for broilers are similar to the original traffic assignment (without considering the impact of congestion) results discussed in Section 5.3.6 (see Figure 5.60), except for the higher volume on US 287 west of Dallas-Fort Worth and a very high volume route passing through Texas from Arkansas. This difference arose because in the original traffic assignment described in Section 5.3.6, only broiler trips originating and/or ending in Texas were considered. Those trips originating and ending in other states were not included in the assignment. However, the research team later found that some of those trips will pass through Texas and therefore cause high truck volume on some Texas roadways. For example, a large number of broilers transported from Arkansas to California pass through Texas panhandle. This is confirmed with the results obtained using Transearch data (see Figure 5.62).

The congestion did have some impact to the results as more roadways are used to transport broilers if we compare Figure 5.64 with Figure 5.60. Also, it can be noticed that IH35 between San Antonio and Dallas-Fort Worth is not as heavily used as before, proving congestion on IH35 make some broiler trucks choose other alternative routes.

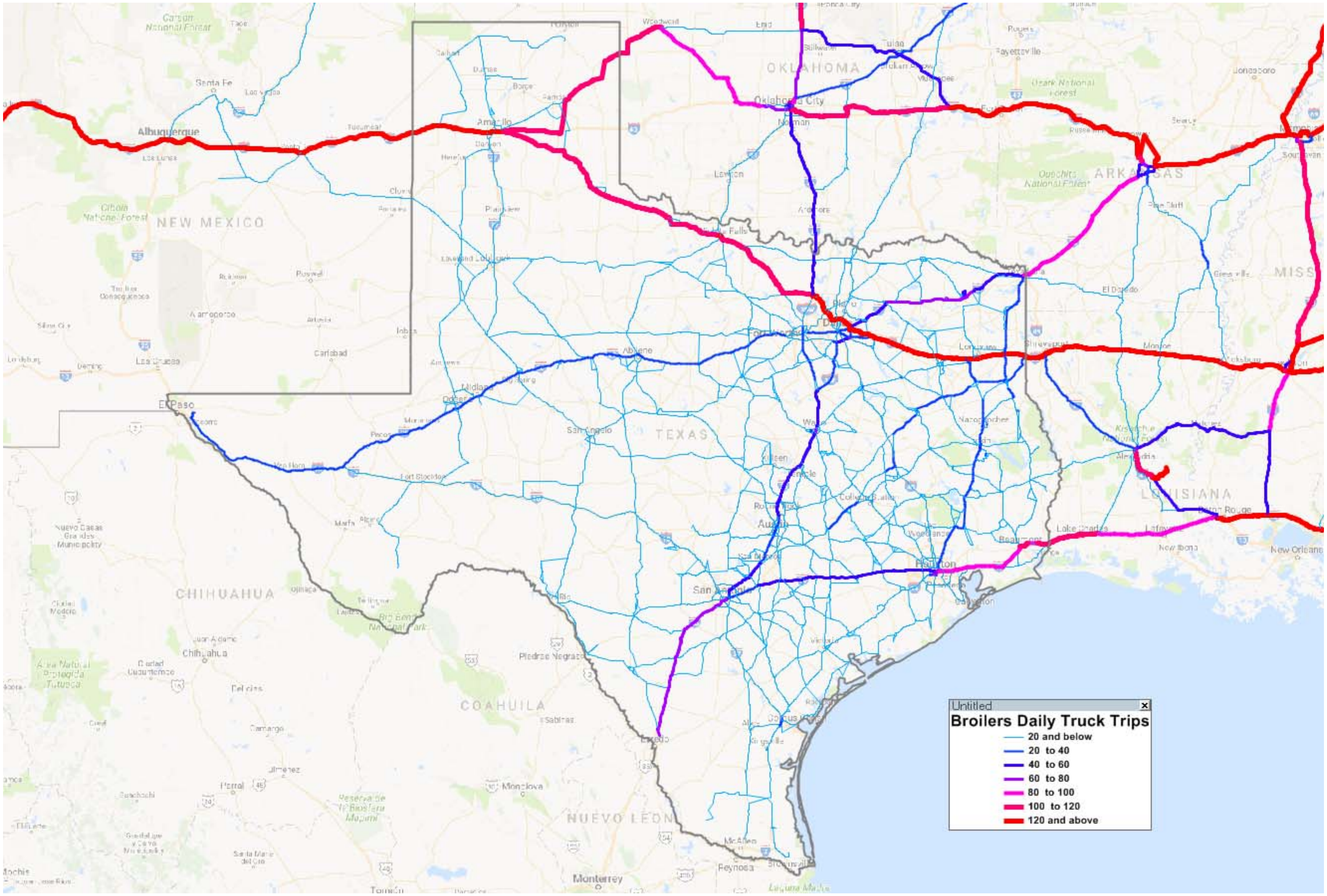


Figure 5.64: Broilers Daily Truck Trips

5.3.10 Summary

In 2013, Texas produced a total of 610.1 million broilers or 3,600 million lbs. This is about 7% of US domestic production. However, due to the extent of international exports that occur in Laredo and El Paso, Texas is a net importer of broilers from other states. Most of the broilers that are imported into Texas come from Arkansas, Mississippi, Alabama, and Georgia. Most of the state exports from Texas go to California.

There are four main broiler companies in Texas (Holmes Foods, Tyson Foods, Sanderson Farms, and Pilgrim's Pride). These four companies have a total of 11 processing plants in Texas. All of these plants are located in the eastern half of the state.

IH 35, IH 10, and US 59 are several major highways used for intrastate broilers movements. IH 40 and US 287 are heavily used by interstate broiler trucks passing through Texas.

No significant seasonal variation of broilers' production, consumption, or movement was observed due to the relatively short life cycle of broilers and stable demand throughout the year.

For future predictions, the same method used for making OD matrices for the year 2013 for broilers can be used. The main issue is having import, export, and production data for the year of interest. One particular source that can be for this is WATT Global Media, which works to connect buyers and sellers in the poultry, pig, animal feed, and pet food industries. WATT Global Media hosts annual webinars that discuss expected supply, demand, and prices for poultry and red meat for the current year and for the following year. Using these predications instead of production, import, and export data from the past, it may be possible to model OD matrices for the current year.

5.4 Eggs

5.4.1 Background

According to the USDA (2015), in 2014, the United States produced just under 100 billion eggs. This includes both hatching (i.e., fertilized) and table eggs. This analysis deals only with table eggs. Although no concrete number was found for the production of table eggs only, the research team was able to estimate the production of table eggs in each state by studying how many egg laying hens each state has. Since the laying rate of the average hen is known (about 0.75 eggs/hen/day as of January 1, 2016) (American Egg Board, 2016), the research team was able to estimate that based on the number of available hens at the beginning of 2016, the United States produced around 80 billion table eggs. Unless otherwise specified, in this "Eggs" section, the *eggs* refers to table eggs only.

Contrary to the broiler supply chain, where the majority of the states are not involved in any sort of mass production, all 50 states have some sort of output of table eggs. The District of Columbia, however, did not mass produce any eggs. The top five egg producing states produced almost 50% of domestic eggs (American Egg Board, 2016). Texas is fifth on the list with approximately 16 million egg laying hens, which translates to almost 4.5 billion eggs per year. Nonetheless, due to Texas' large demand, Texas still imports more eggs from other states than it exports to them.

In fact, there are only 15 states that are net exporters to other states while Texas, the District of Columbia, and 34 other states have to rely on imports. Figure 5.65 shows the states that whose broiler production exceeds their demand from international exports plus their demand to satisfy their own population.

Figure 5.65: States that Are Able to Satisfy the Entire Demand for All of Their International Exports plus Their Population

Also contrary to the broiler supply chain, the egg commodity is much more volatile due to a low unit value (price of one egg). Due to a low unit value, small market changes can have a great impact on the ability for a company to make a profit and thus egg producing companies have to continually be taking proactive measures to ensure success. For example, eggs may travel a far distance during times of high demand and when fuel costs are low. However, if demand is low and fuel costs are high, then producers will not be willing to ship eggs to a faraway location.

In this analysis, the research team does not differentiate between shell eggs and further processed eggs. While shell eggs are the normal everyday eggs one might find in the store, further processed eggs are eggs that are generally either hard boiled or broken for separation of the yolk (yellow) from the albumen (white). The reason why the research team did not differentiate between these two types is because, usually, further processing occurs at the same facility as where the shell eggs are processed.

However, it is true that further processed eggs may often have a different target audience than shell eggs. For example, further processed eggs may be a lot more common in the food service industry. Nonetheless, because the research team assumes that the locations of food service businesses are in direct correlation with population, the destination of different egg types (shell or further processed) should be similar.

5.4.2 Supply Chain

Much like in the broiler industry, most large egg companies are vertically integrated. They are in charge of rearing, feeding, housing, husbandry, egg collection, processing, packaging, and distribution (Meunier & Latour, 2015). Only the parent breeding stock may commonly be provided by another company.

The supply chain for eggs is simple and straightforward. Prior to the hens reaching the laying facilities, the supply chain is similar to the broiler supply chain. This means that hens are raised on other facilities until they are ready to lay eggs. Once ready, they are transferred to an egg layer facility.

There are two main types of egg layer facilities that are the primary focus of the supply chain—the "in-line" and "off-line" facilities. In the in-line facilities, hens will lay eggs onto a slightly angled wire floor that allows the eggs to roll onto a nylon belt. The belt then transports the eggs to the egg processing facility on-site. Inside the processing facility, the eggs are washed, visually inspected, graded for packaging, packaged, and moved to a cooler where they are stored until they are taken to retail, a foodservice business, or for export (Meunier & Latour, 2015).

In the off-line facility, after eggs are collected, rather than taking them to processing on a nylon belt, they are temporarily stored inside a cooler for a few days. Once enough eggs accumulate in the cooler, they are taken to an egg processing facility via a refrigerated truck. Once at the in-line facility, the eggs are treated the same as those from the in-line operations (Meunier & Latour, 2015).

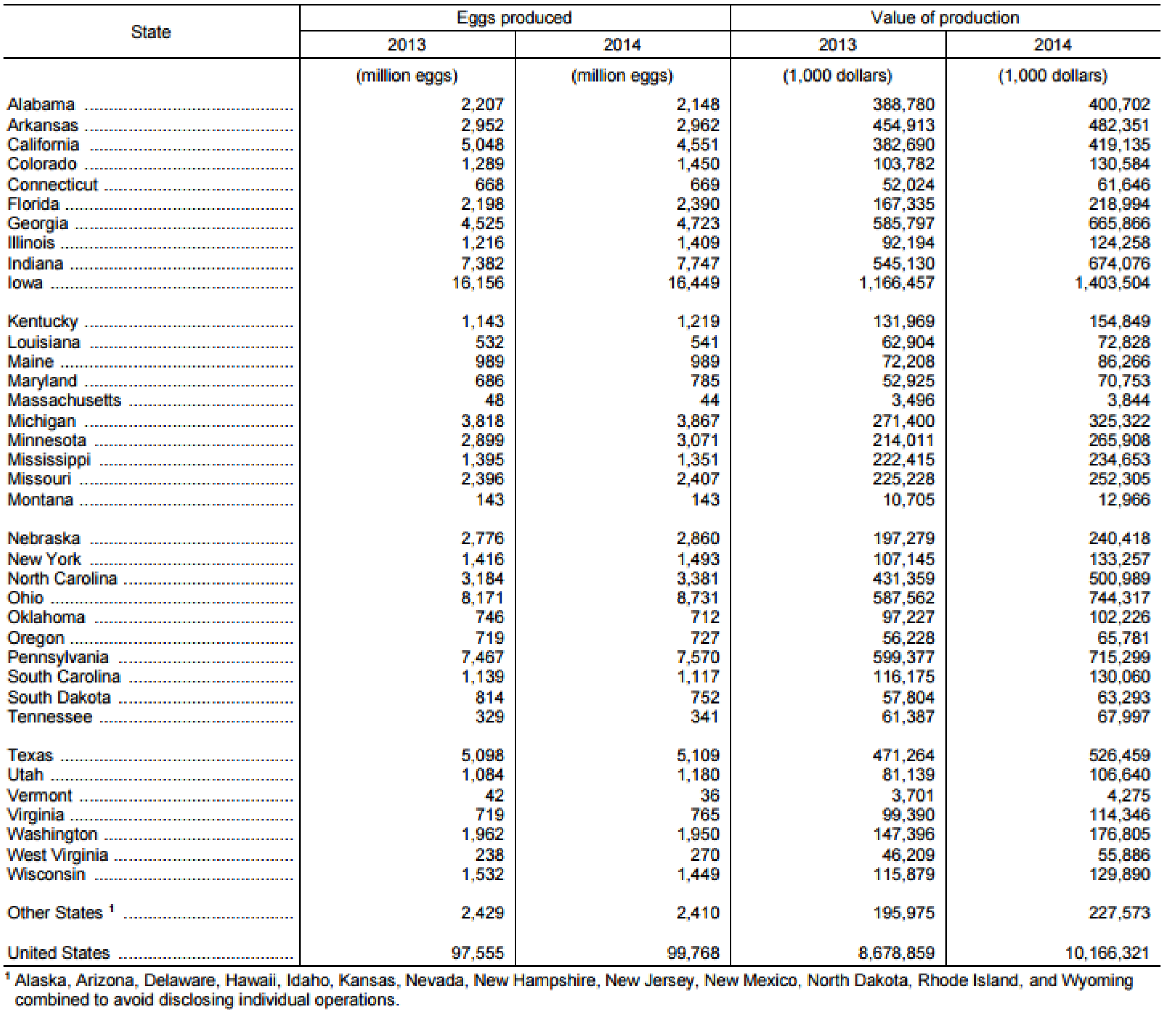
Generally, in-line facilities are bigger. The reason why off-line facilities do not process their own eggs is because they don't generate enough eggs to make it economically profitable. In addition, it is at the "in-line" facility where eggs are graded. In order for eggs to be graded, they must have an "egg license" from the TDA. Egg licenses are a very important source of data as discussed in the dataset section.

5.4.3 Datasets

Using experience acquired during the modeling of broilers, the research team understood that it would most likely not be possible to try to study the plethora of individual egg companies in the US to find where they have facilities and the production amount of each facility. Instead, the research team focused on aggregated egg production for all states other than Texas. For Texas, the locations of the individual processing facilities are important. In addition, using USA Trade Data, the research team was able to find the amount of exports and imports in each state.

USDA State Production Data

As with broilers, one of the most important data sets used was provided by the USDA, which gives the production of eggs by state for the years 2013 and 2014. Figure 5.66 indicates that in 2014 Texas produced 5.1 billion eggs.



State	Eggs produced		Value of production	
	2013	2014	2013	2014
	(million eggs)	(million eggs)	(1,000 dollars)	(1,000 dollars)
Alabama	2,207	2,148	388,780	400,702
Arkansas	2,952	2,962	454,913	482,351
California	5,048	4,551	382,690	419,135
Colorado	1,289	1,450	103,782	130,584
Connecticut	668	669	52,024	61,646
Florida	2,198	2,390	167,335	218,994
Georgia	4,525	4,723	585,797	665,866
Illinois	1,216	1,409	92,194	124,258
Indiana	7,382	7,747	545,130	674,076
Iowa	16,156	16,449	1,166,457	1,403,504
Kentucky	1,143	1,219	131,969	154,849
Louisiana	532	541	62,904	72,828
Maine	989	989	72,208	86,266
Maryland	686	785	52,925	70,753
Massachusetts	48	44	3,496	3,844
Michigan	3,818	3,867	271,400	325,322
Minnesota	2,899	3,071	214,011	265,908
Mississippi	1,395	1,351	222,415	234,653
Missouri	2,396	2,407	225,228	252,305
Montana	143	143	10,705	12,966
Nebraska	2,776	2,860	197,279	240,418
New York	1,416	1,493	107,145	133,257
North Carolina	3,184	3,381	431,359	500,989
Ohio	8,171	8,731	587,562	744,317
Oklahoma	746	712	97,227	102,226
Oregon	719	727	56,228	65,781
Pennsylvania	7,467	7,570	599,377	715,299
South Carolina	1,139	1,117	116,175	130,060
South Dakota	814	752	57,804	63,293
Tennessee	329	341	61,387	67,997
Texas	5,098	5,109	471,264	526,459
Utah	1,084	1,180	81,139	106,640
Vermont	42	36	3,701	4,275
Virginia	719	765	99,390	114,346
Washington	1,962	1,950	147,396	176,805
West Virginia	238	270	46,209	55,886
Wisconsin	1,532	1,449	115,879	129,890
Other States [1]	2,429	2,410	195,975	227,573
United States	97,555	99,768	8,678,859	10,166,321

[1] Alaska, Arizona, Delaware, Hawaii, Idaho, Kansas, Nevada, New Hampshire, New Jersey, New Mexico, North Dakota, Rhode Island, and Wyoming combined to avoid disclosing individual operations.

Figure 5.66: Eggs[12] Laid by State in 2013 and 2014

The main problem with this data is that it provides the total number of eggs laid by state regardless of whether they are hatching eggs or table eggs. This is why Figure 5.66 reports that in 2014 the US produced almost 100 billion eggs (hatching and table), but the actual number is much closer to 81 billion table eggs since the other roughly 19 billion eggs are fertilized. Thus, in order to predict table egg values from the data provided by the USDA, another source was needed, which is the American Egg Board Data.

American Egg Board Data

The American Egg Board provides a plethora of information in order to gain understanding of the egg supply chain. However, the most important bit of information provided is the top ten egg producing states ranked by the number of hens that the state has. By knowing the average laying rate per hen, which according the American Egg Board (2016) is 0.75 eggs per hen per day, it is possible to predict the number of eggs laid in 2015 in each of these ten states as shown in Table 5.12.

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[12] This includes table eggs and hatching eggs.

Table 5.12: Ten egg producing states ranked by the number of hens owned and the associated predicted number of eggs laid in 2015

State	Number of Hens (in thousands)	Predicted Number of Eggs Laid (in millions)
Iowa	36,733	10,029
Ohio	30,786	8,405
Indiana	29,364	8,017
Pennsylvania	23,863	6,515
Texas	16,368	4,469
Michigan	12,922	3,528
California	11,821	3,227
Georgia	10,462	2,856
Minnesota	8,961	2,447
Florida	8,784	2,398
Ten State Total	**190,064**	**51,891**

Together, the ten states shown in Table 5.12 produced a total of 51,891 million table eggs, while Figure 5.66 indicates that the total number of eggs laid for these ten states is 64,208 million. This suggests that, on average, for every 100 eggs laid in the US, 81 of them are table eggs and the other 19 are hatching eggs. Using this logic, all states not specifically shown in Table 5.12 use a conversation rate of 0.81 to predict how the egg numbers reported in Figure 5.66 are to be used to predict the number of table eggs laid in 2015.

It needs to be noted that Figure 5.66 data are from 2013 and 2014 while Table 5.12 data are for 2015. Thus, the assumption has to be made that production from 2014 to 2015 stayed the same. It is reasonable to think that the amount of error introduced through this assumption is relatively low since the total number of eggs produced in the US between 2013 and 2014 increased by about 2%. A small increase between 2014 and 2015 could also be expected.

USA Trade Data

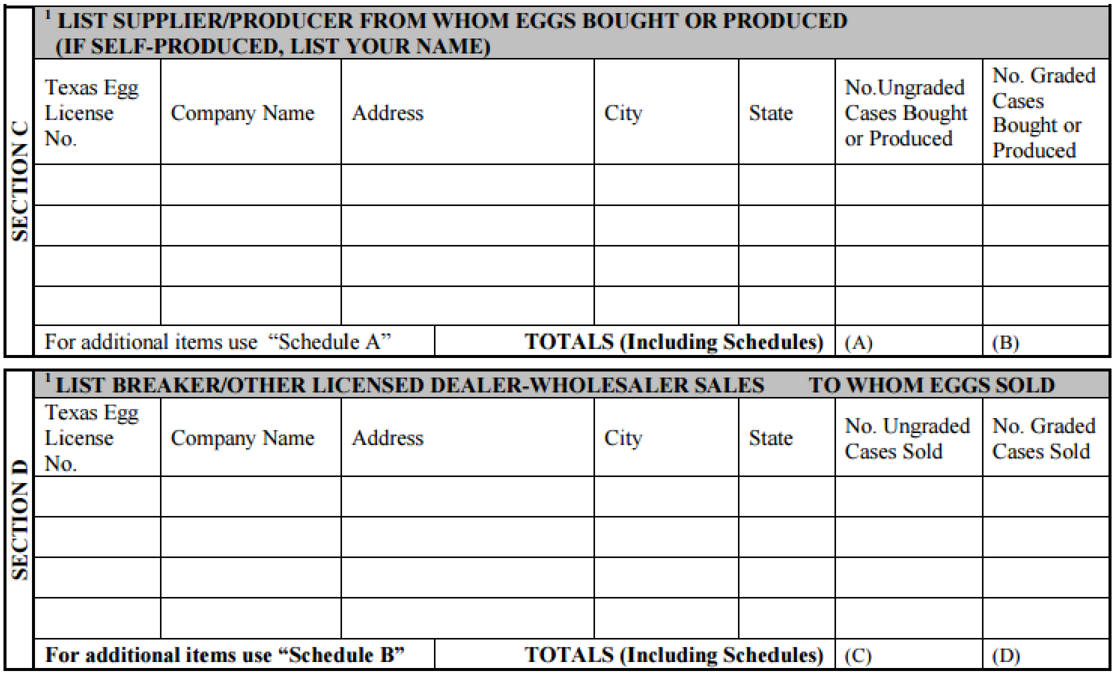
USA Trade Data provided the research team with the monetary value of egg products imported and exported into the US by state. As with all other commodities retrieved from USA Trade Data, the reported weight is the shipping weight (which includes the commodity of choice and any associated packaging). Thus, in order to estimate the actual number of eggs imported and exported, the unit price of a dozen eggs was set at $0.61. This number was chosen based upon the average wholesale price of a dozen eggs in April 2016 (USDA, 2016). However, as previously stated, because the egg industry can be volatile, this price point is only an estimate that is constantly changing based on time and region.

In order to validate the wholesale price used, it was found that this price results in an estimate of 3.6 billion eggs exported in 2015 compared to a domestic production of 80.6 billion eggs or 4.5% of production. According to the American Egg Board (2016), in 2014, 4.7% of eggs were exported. Assuming a similar trend into 2015, this yields two very similar values.

Texas Department of Agriculture

Perhaps the most important source for understanding the flow of eggs in Texas came from the TDA. TDA requires that egg dealers/wholesaler, egg processors, and egg brokers all have “Egg

Licenses.” Essentially this means that anyone who buys eggs for the sake of reselling them, anyone who grades eggs, and anyone that processes eggs must have an Egg License. As part of the Egg License, the company must report on a quarterly basis how many cases of eggs it bought or sold and from whom. There are a few different forms depending on whether the company is a producer or dealer/wholesaler. An example of such a form is found in Figure 5.67.



SECTION C

[1] LIST SUPPLIER/PRODUCER FROM WHOM EGGS BOUGHT OR PRODUCED (IF SELF-PRODUCED, LIST YOUR NAME)

Texas Egg License No.	Company Name	Address	City	State	No.Ungraded Cases Bought or Produced	No. Graded Cases Bought or Produced
For additional items use “Schedule A”				**TOTALS (Including Schedules)**	(A)	(B)

SECTION D

[1] LIST BREAKER/OTHER LICENSED DEALER-WHOLESALER SALES TO WHOM EGGS SOLD

Texas Egg License No.	Company Name	Address	City	State	No. Ungraded Cases Sold	No. Graded Cases Sold
For additional items use “Schedule B”				**TOTALS (Including Schedules)**	(C)	(D)

Figure 5.67: Excerpt from Form REG-203 from the TDA that Requires the Reporting of Eggs Bought and Sold by Wholesalers

By issuing a request for public information, the research team was able to find the number of cases processed for fiscal year 2015 for the 13 egg processing plants that are listed by the USDA as participating in USDA’s voluntary poultry and egg grading certification services. The amount of production by these 13 plants is shown in Table 5.13.

Table 5.13: Amount of cases produces by 13 egg processing plants in Texas in 2013[13]

Company and County	Volume Cases FY 2015	Number of Eggs 2015 (Millions)
Feather Crest Farms / Brazos County	217,951	78
Cal-Maine Farms, Inc. / Gonzales County	679,399	245
Mahard Egg Farm, Inc. / Hardeman County	918,498	331
Cal-Maine Foods, Inc. / Gonzales County	686,996	247
Cal-Maine Foods, Inc. / Fayette County	1,051,107	378
Cal-Maine Foods, Inc. / Gonzales County	727,210	262
Cal-Maine Foods, Inc. / Fayette County	1,038,634	374
Cal-Maine Foods, Inc. / Parmer County	-	-
Cal-Maine Foods, Inc. / Camp County	701,651	253
Cal-Maine Foods, Inc. / Camp County	748,372	269
Wharton County Foods LLC / Wharton County	1,642,184	591
Wharton County Foods LLC / Wharton County	1,137,154	409
Soncrest Egg Company / Gonzales County	101,763	37
Total	9,650,917	3,474

It is interesting to note that the Cal-Maine Foods facility in Parmer County did not produce any egg in 2015. The reason for this is not known but there are a number of possibilities, including the fact that the demand for far west Texas (Parmer County is in the Texas Panhandle) and the surrounding region was not high enough in 2015 to justify an investment to operate the facility. A satellite view of this facility was examined and it appeared to be in good shape; thus, the possibility that the facility is no longer operating because it is not being maintained does not seem likely.

The total number of eggs reported between these 13 facilities is just under 3.5 billion. However, earlier, it was shown that in 2015 Texas produced just under 4.5 billion eggs. This leaves just under 1 billion eggs whose origin is not accounted for. To navigate this issue, the research team implemented a temporary solution and can implement a much better, but more expensive, permanent solution if given the direction to do so. Following are the two solutions:

- Temporary solution: scale up each of the 13 facilities listed in Table 5.13 by 1.28. This assumes that all of the 1 billion missing eggs are dispersed amongst the 13 facilities proportional to their 2015 production.
- Permanent solution (if desired): In exchanging emails with Jessica Escobar of the TDA, it was made clear that the research team could request public information for all of the companies in 2015 that were involved in the selling, grading, and processing of eggs. This would allow the research team to know not only where else eggs were produced but also who bought them and who sold them. This would drastically improve the results of the gravity model that the research team used. However, the main disadvantage to this permanent solution is that it is expensive to process. On April 21, 2016, the research team received a quote from the TDA outlining the costs of performing this work; the total fee is $2194.00, which is broken up into 83 hours of personnel time ($15/hr), 7000 black and white copies ($0.10/page), and 83 hours of overhead charge ($3/hr). This quote is valid

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[13] According to the TDA, one case is equivalent to 30 dozen eggs.

for 10 business days and will require a new quote afterwards. For now, the modeling presented in the following section is based off of the 13 facilities listed in Table 5.13.

5.4.4 Commodity Flow Estimation

The data sources discussed provide information on egg production by state (from the USDA and the American Egg Board), egg imports and exports by state (from USA Trade), and locations and quantities of egg production in Texas. By using production data and import/export data, it is possible to calculate the average egg consumption per capita. This is similar to what has been done with other commodities such as broilers.

Based on these data sources, the research team found that the demand per capita per year is 245 eggs for 2015—about 2% lower than the number reported by the American Egg Board (2016) of 250 eggs per capita per year. This value does not reflect the number of eggs actually eaten by the average American each year, as only 54.9% of table eggs (as of 2014) make it to retail in their shells (American Egg Board, 2016). The other 45.1% are taken for further processing, sold to foodservice businesses, or exported. Nonetheless, this value of 245 eggs provides an approximation of demand for each county, based on population.

Next, the supply and demand for each state was found using the same methods for calculating broiler supply and demand. For each state, the research team found the annual egg demand by taking the per capita demand and multiplying it with each state's population and then adding the amount of eggs that need to be exported from each state's ports. Similarly, each state's supply was found by taking the production of each state and adding to it the amount of eggs imported through all the ports in that state.

Then, a state-to-state OD Matrix was developed by applying a gravity model based off the distance between each state. Since minimizing the distance traveled is very important in the egg industry, due to the high costs of transport and low unit costs of eggs, the research team assumes that there is no state-to-state OD pair that has eggs going in each direction. This means, for example, that rather than having State A ship 10 million eggs to State B and having State B ship 3 million eggs to State A, extra care was taken to make sure the model outputs something more realistic; in this case, it would mean that State A ships 7 million eggs to State B while State B does not ship any eggs to State A. Using this gravity model, Table 5.14 shows the top five states that Texas exports to and the top five states that Texas imports from for the year 2015. Also, about 3.8 billion eggs start and end in Texas.

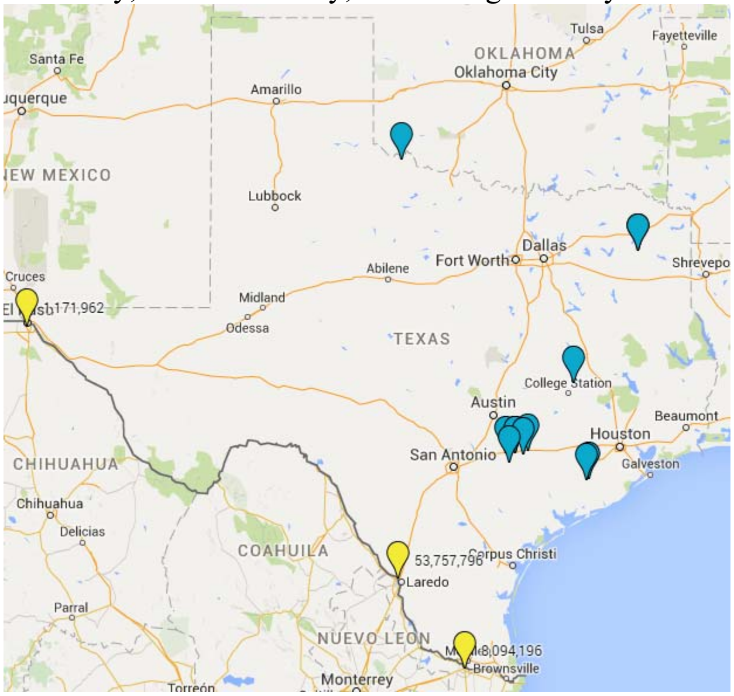
Table 5.14: Top five states that Texas exports to and imports from

	Exports out of Texas (M Eggs)		**Imports into Texas (M Eggs)**
Total	**710.3**	**Total**	**3,473.8**
California	326.2	Iowa	804.3
Arizona	72.3	Indiana	468.6
Tennessee	44.2	Ohio	398.9
Massachusetts	34.5	Arkansas	322.2
Louisiana	30.4	Nebraska	192.1

Just as with some other commodities, including broilers, the interstate border crossing used to deliver eggs into/out of Texas is not known. For this reason, only the internal-internal OD Matrix for eggs is calculated.

In order to model just internal-internal OD matrices, the research team assumed that only 52% of the demand for each county needs to be met. This is because the other 48% of the demand will be met by external production. Likewise, only 84% of Texas' supply will be used to satisfy internal demand since the other 16% will be used to go to other states. In the Broiler section of this report, the reasoning behind these reduction factors is explained more in-depth.

Using this approach, there are a total of nine counties where eggs may originate. These nine counties include six counties where broilers are being processed and three counties where broilers are being imported from out of the country. Thus, the County-to-County OD Matrix that is 254 x 254 for Texas will actually only have 9 rows since all the other rows will be zero. These nine origin points are shown in Figure 5.68. Blue markers represent processing locations while the yellow markers represent locations where eggs are imported from Mexico. The three counties that import eggs are Webb County, El Paso County, and Hidalgo County.



(Blue markers = processing locations; yellow markers = locations where eggs are imported from Mexico)

Figure 5.68: Counties in Texas with Egg Sources

Just as with broilers, the same adjustment in demand was performed for eggs; counties that are not able to serve much of their populations with grocery stores had their demand reassigned to other counties, as was shown in Figure 5.54. Indeed, for simplicity in modeling, any agricultural product that is going to retail and is modeled using a gravity model should take care to not serve the dark green counties shown in Figure 5.54. If it does, there will be many cells in the OD matrix that appear to import just a little bit of agriculture from all around the state, which is not very realistic.

Also, just as with broilers, counties that import eggs from abroad were assumed to keep those eggs within the county. This is because there are very few egg products imported into Texas (found only in the El Paso, Hidalgo, and Webb counties) and thus it does not make sense to distribute these few products throughout the state.

5.4.5 Transportation

Truck Type

Eggs are almost always transported in refrigerated trucks; beginning in 1999, the FSIS required that all shell eggs packed for consumers to be transported at an ambient temperature not to exceed 45°F (FSIS, 2013). The size of the truck may vary based on the company and the amount being shipped. In addition, if instead of shell eggs, the product being transferred is processed egg products, they may be transferred via a bulk semi-trailer, such as the one shown in Figure 5.69 (Meunier & Latour, 2015). In addition, for shell eggs, containers, packaging, and securing must be such that the eggs are well protected against mechanical damage.

Figure 5.69: Bulk Semi-trailer Used to Transport Processed Egg Products

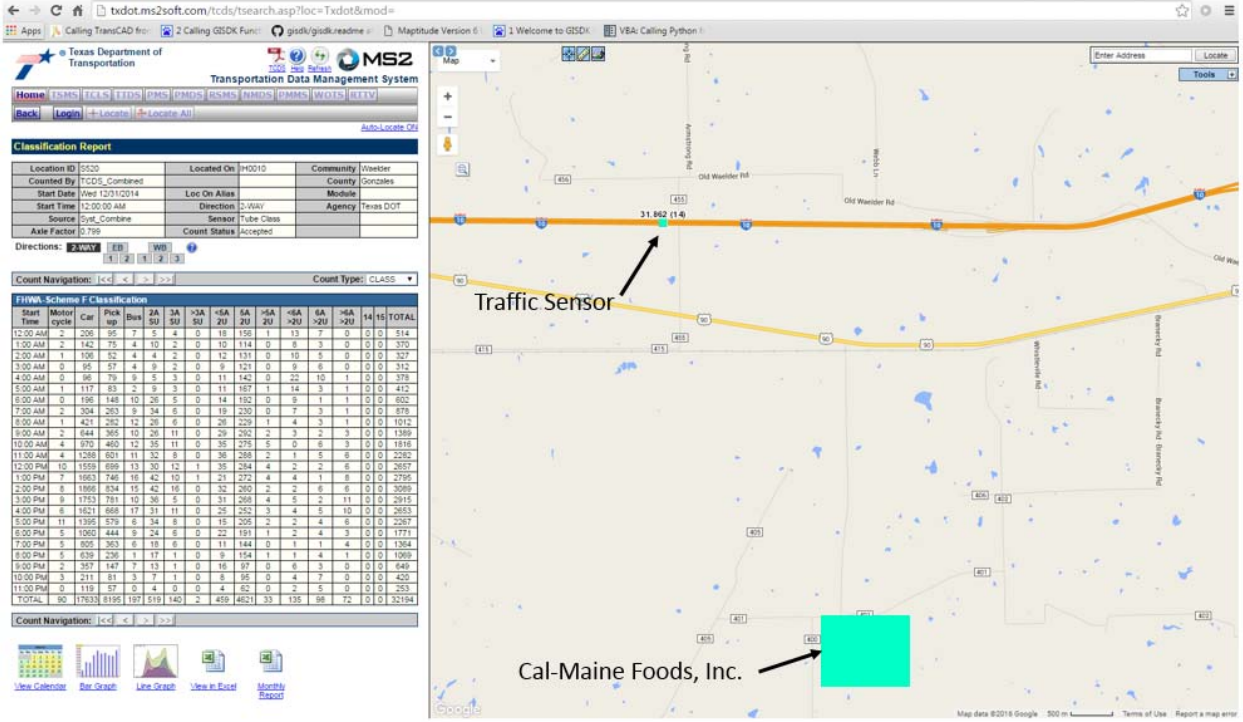
The truck most often used for transporting processed eggs from processing plants to market, which includes retail, distributors, wholesalers, etc., is the Class 9 single trailer five-axle truck, as shown in Figure 5.55. The research team spoke with a representative from the US Poultry & Egg Association whose main area of expertise is poultry; as noted in the broiler section, he estimates that for broilers the Class 9 truck is used about 95% of the time. In the other 5% of the cases, he estimates that a Class 6 single unit three-axle truck, shown in Figure 5.56, is used most often. Though he does not work in the egg division, he supposed that the truck distribution for broilers and eggs is similar. Nonetheless, because eggs are not his primary area of focus, the research team looked for additional sources for input.

To further support the idea that Class 9 trucks are most often used, three exercises were performed. As an initial exercise, the research team conducted an internet search and found that photos available online of egg trucks were most commonly Class 9. An example of such trucks, owned by Hillandale Farms, is shown in Figure 5.70.

Figure 5.70: Class 9 Trucks Used to Transport Eggs

Second, TxDOT's Transportation Data Management System has sensors throughout the state to count traffic, often by vehicle type. In one particular location, shown in Figure 5.71, a traffic sensor is placed very close to a Cal-Maine Foods, Inc. processing facility. On a randomly chosen day, this sensor identified 76% of trucks as Class 9 single trailer five-axle trucks. No other truck type was seen more than 9% of the time. If Cal-Maine Food, Inc. used another truck type more often than Class 9, one would expect to see a higher proportion of another truck class to cross the nearby traffic sensor. None of the other traffic sensors available through the Data Management System were close to an egg processing facility, so the research team was unable to repeat this exercise.

Lastly, the research team explored satellite views of each of the egg processing facilities in Texas. It was found that the majority of freight vehicles located on the premises of the processing facilities most often resembled a Class 9 single trailer five-axle truck. An example is shown in Figure 5.72, where every single freight vehicle seems to be a Class 9 truck. This particular facility is located in Boling, TX.



Classification Report

Location ID	S520	Located On	IH0010	Community	Waelder
Counted By	TCDS_Combined			County	Gonzales
Start Date	Wed 12/31/2014	Loc On Alias		Module	
Start Time	12:00:00 AM	Direction	2-WAY	Agency	Texas DOT
Source	Syst_Combine	Sensor	Tube Class		
Axle Factor	0.799	Count Status	Accepted		

FHWA-Scheme F Classification

Start Time	Motor cycle	Car	Pick up	Bus	2A SU	3A SU	>3A SU	<5A 2U	5A 2U	>5A 2U	<6A >2U	6A >2U	>6A >2U	14	15	TOTAL
12:00 AM	2	206	95	7	5	4	0	18	156	1	13	7	0	0	0	514
1:00 AM	2	142	75	4	10	2	0	10	114	0	8	3	0	0	0	370
2:00 AM	1	106	52	4	4	2	0	12	131	0	10	5	0	0	0	327
3:00 AM	0	95	57	4	9	2	0	9	121	0	9	6	0	0	0	312
4:00 AM	0	96	79	9	5	3	0	11	142	0	22	10	1	0	0	378
5:00 AM	1	117	83	2	9	3	0	11	167	1	14	3	1	0	0	412
6:00 AM	0	196	148	10	26	5	0	14	192	0	9	1	1	0	0	602
7:00 AM	2	304	263	9	34	6	0	19	230	0	7	3	1	0	0	878
8:00 AM	1	421	282	12	26	6	0	26	229	1	4	3	1	0	0	1012
9:00 AM	2	644	365	10	26	11	0	29	292	2	3	2	3	0	0	1389
10:00 AM	4	970	460	12	35	11	0	35	275	5	0	6	3	0	0	1816
11:00 AM	4	1288	601	11	32	8	0	36	288	2	1	5	6	0	0	2282
12:00 PM	10	1559	699	13	30	12	1	35	284	4	2	2	6	0	0	2657
1:00 PM	7	1663	746	16	42	10	1	21	272	4	4	1	8	0	0	2795
2:00 PM	8	1866	834	15	42	16	0	32	260	2	2	6	6	0	0	3089
3:00 PM	9	1753	781	10	36	5	0	31	268	4	5	2	11	0	0	2915
4:00 PM	6	1621	668	17	31	11	0	25	252	3	4	5	10	0	0	2653
5:00 PM	11	1395	579	6	34	8	0	15	205	2	2	4	6	0	0	2267
6:00 PM	5	1060	444	9	24	6	0	22	191	1	2	4	3	0	0	1771
7:00 PM	5	805	363	6	18	6	0	11	144	0	1	1	4	0	0	1364
8:00 PM	5	639	236	1	17	1	0	9	154	1	1	4	1	0	0	1069
9:00 PM	2	357	147	7	13	1	0	16	97	0	6	3	0	0	0	649
10:00 PM	3	211	81	3	7	1	0	8	95	0	4	7	0	0	0	420
11:00 PM	0	119	57	0	4	0	0	4	62	0	2	5	0	0	0	253
TOTAL	90	17633	8195	197	519	140	2	459	4621	33	135	98	72	0	0	32194

Figure 5.71: Location of Traffic Sensor to Count Vehicle Classes Compared to Cal-Maine Foods Processing Facility

Figure 5.72: Satellite View of a Part of the Wharton County Foods LLC Processing Facility; All Freight Vehicles Visible Are Class 9 Single Trailer Five-axle Trucks

For these three reasons, the research team decided to proceed by assuming a Class 9 truck is used most of the time. As with broilers, Class 6 was still assumed to be used some of the time so that smaller loads to smaller communities could be delivered efficiently.

Again, as with broilers, the research team assumed that Class 6 trucks are never used for interstate shipping of eggs. Interstate shipping implies long-distance travel where the profit margins are very small, and thus small shipments are very unlikely. This is an even bigger issue for eggs than for broilers because eggs have even lower profit margins. Indeed, Professor Coufal from the TAMU Department of Poultry Science told the research team that even small changes in fuel prices can greatly affect how far egg companies are willing to ship their product.

Therefore, just as with broilers, the researchers determined that interstate shipping only uses Class 9 trucks while intrastate shipping uses both Class 9 and Class 6 trucks.

Truck Capacity

According to the USDA (2016), one standard shipping case used holds 30 dozen eggs. With that, 600 standard-sized cases make one trailer load. This means that one typical trailer for a Class 9 truck will carry about 216,000 eggs. Since the original OD matrix estimated is based on the number of eggs transported, this figure is all that the matrix needs to calculate truck trips. However, we felt it prudent to ensure that 216,000 eggs is a feasible load for one trailer.

To that end, we performed the following calculations. The USDA has requirements regarding the minimum allowable weight per dozen eggs. For example, for "jumbo" and "extra large" eggs, the minimum allowable weight is 30 and 27 ounces per dozen eggs, respectively (USDA, 2016). Since this is only the minimum weight, there must be additional allowance for a few extra ounces. Also, we must allow another few ounces for filler material and cases. Therefore, using a gross average weight per dozen eggs of 36 ounces, one trailer load with 216,000 eggs will weigh 40,500 lbs. Since this is about the expected amount that a Class 9 truck will carry, we determined that a Class 9 truck would reasonably carry 216,000 eggs. Similarly, the capacity of a Class 6 truck will be 108,000 eggs (which equates to 20,250 lbs at 36 ounces per dozen).

Converting Tonnage to Equivalent Trucks

The research team found the number of equivalent truck trips using the same procedure as for broilers:

- For state-to-state shipping, it was assumed that each truck carried 216,000 eggs (or egg equivalents).
- For county-to-county shipping:
  - If the total amount being shipped from one county to another was less than 216,000 eggs, then it is assumed that all product is shipped via one or two Class 6 trucks that can each carry about 20,000 lbs.
  - If the total amount being shipped from one county to another was greater than 216,000, then it is assumed that 99.5% of the total eggs are assigned to Class 9 trucks that carry an average of 40,000 lbs. Class 6 trucks, with a capacity of about 20,000 lbs, are used to transport 0.5% of the total eggs.

- Previous two steps result in Class 6 trucks being used roughly 6% of the time, which is close to the 5% previously mentioned in the "Truck Type" section, just as with broilers.

Estimating Empty Trucks

In the case of state-to-state shipping, it is assumed that none of the trucks return empty. The reason for this assumption is the same as what is listed in the section for broilers; the underlying reason is that companies will not be profitable if they allow a large number of empty return trips.

In the case of county-to-county shipping, it has been found that Cal-Maine Farms, Inc. and Mahard Egg Farm, Inc. have their own fleet of trucks. The research team did not find that Feather Crest Farms, Wharton County Foods LLC, and Soncrest Egg Company have their own fleet. Therefore, trips that start from Cal-Maine Farms, Inc. or Mahard Egg Farm, Inc. are said to have empty return trips. Trips for the other companies do not have empty return trips. If new information arises to show that one of the companies assumed not to have their own fleet, does indeed have their own fleet, the model developed can be easily adjusted.

Results

Full results, showing the number of truck trips from county to county and state to state, are included in Appendix 1 of this report. Tables 5.15 and 5.16 provide a brief summary for Texas.

Table 5.15: Total number of loaded Class 9 trucks for the top five states that trade with Texas modeled for 2013 for travel (a) to Texas and (b) from Texas, rounded to the nearest hundred

Iowa	3,700
Indiana	2,200
Ohio	1,800
Arkansas	1,500
Nebraska	900

(a)

California	1,500
Arizona	300
Tennessee	200
Massachusetts	200
Louisiana	100

(b)

Table 5.16: Total number of loaded trucks (irrespective of class) modeled for 2013 that travel between the origin (rows) and the top five destinations[14] in Texas (columns)

	Harris County	Dallas County	Webb County	Tarrant County	Bexar County
Brazos County	65	38	19	30	18
Camp County	203	433	91	274	67
Fayette County	611	289	240	233	266
Gonzales	477	268	326	221	466
Hardeman	97	196	77	180	54
Webb County	0	0	251	0	0
Wharton	1265	316	305	249	256
Total	**2718**	**1540**	**1309**	**1187**	**1127**

5.4.6 Network Analysis

The truck trips for the transport of eggs from processing plants to retail wholesale estimated in the previous section are assigned to the created freight network following the procedure described in Section 4.3. Results are represented in Figure 5.73 (Class 6 truck), Figure 5.74 (Class 9 truck), and Figure 5.75 (total).

Figure 5.73 indicates that, similar to broilers, Class 6 egg truck trips are also mostly concentrated in between the big cities. Some sections of US 287 between Dallas-Fort Worth and Amarillo and IH 35 between Austin and Dallas-Fort Worth carry the highest number of Class 6 egg trucks, but the number was low, only about 180 trucks annually. US 271 between Tyler and Mt. Pleasant, a section of IH 10 east of San Antonio, and a section of US 59 west of Houston also carry a relatively high number of Class 6 trucks. However, as most of eggs are transported by Class 9 trucks, the number of Class 6 egg trucks on the network is very small.

As is the case with broilers, the majority of interstate egg transportation and all state-to-state egg transportation use Class 9 trucks. As shown in Figure 5.74, most eggs imported into Texas come into Dallas from Iowa, Kansas, and Oklahoma via IH 35. IH 35 between Austin and Dallas-Fort Worth is an important corridor for interstate egg transportation. IH 10 carries many Class 9 egg trucks for exporting eggs from Texas to California. As Class 9 trucks are the prominent mode of transporting eggs, the network pattern of total truck trips is very similar to that of Class 9 trucks, except that the number of trucks will be slightly higher.

The value of eggs used in this study is $1.91/dozen, estimated using the US Bureau of Labor's historic data of 2013 egg prices (US Bureau of Labor Statistics). The value is calculated by averaging twelve monthly egg prices in 2013. The research team chose 2013 pricing because the egg flow matrix developed in previous sections was based on 2013 data. Based on this value, a Class 9 truck carrying 18,000 dozen eggs would be worth $34,380 and a Class 6 truck carrying 9,000 dozen eggs would be worth $17,190.

Figure 5.76 depicts the estimated value (in thousands) of egg movements on the freight network. IH 35 is the primary corridor for transporting eggs. The movement of eggs on IH 35 between Austin and Dallas-Fort Worth and from Dallas-Fort Worth to Oklahoma City is worth more than $240 million annually.

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[14] These five counties require just over 40% of all the truck trips modeled for Texas.

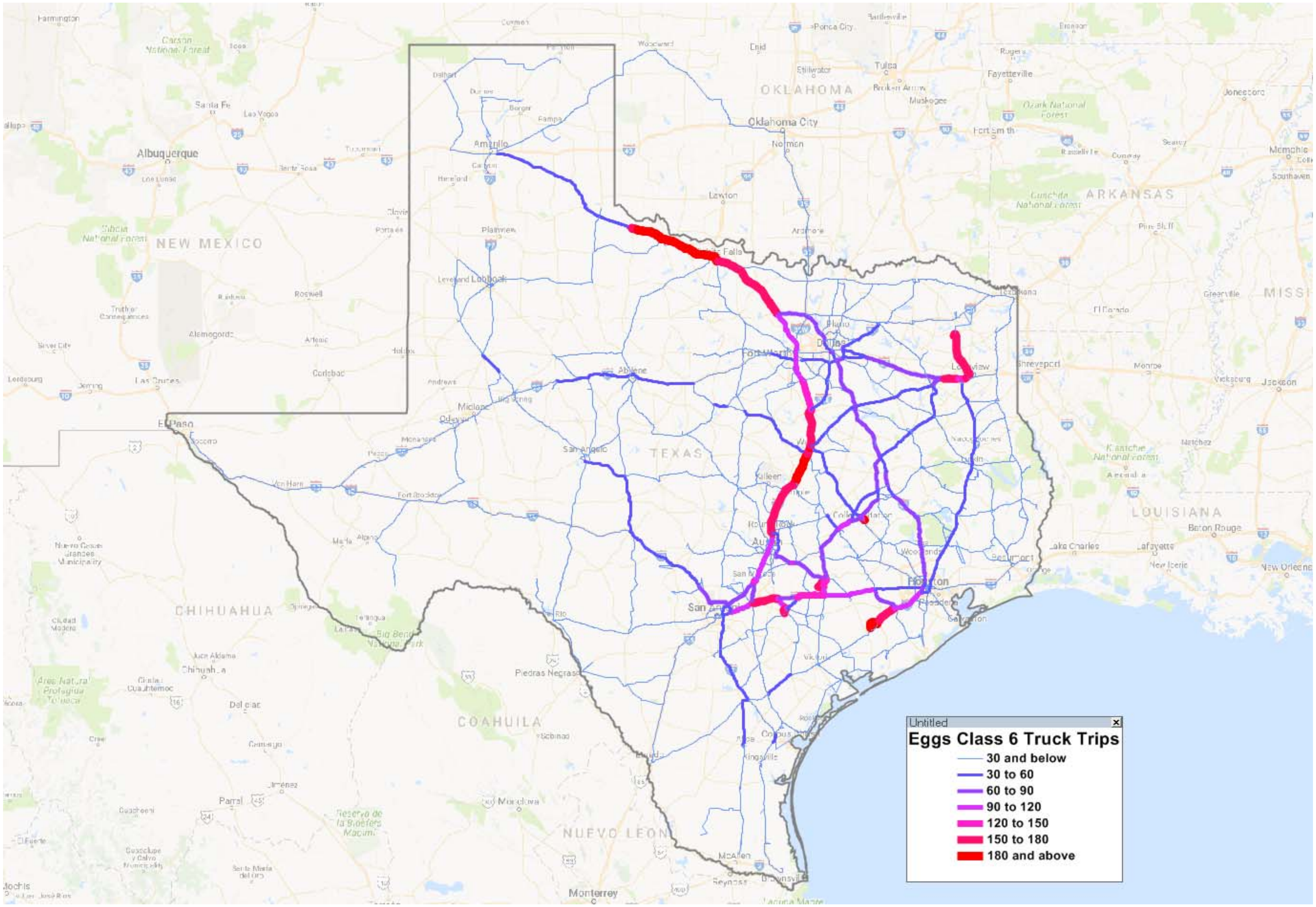

Figure 5.73: Eggs Class 6 Truck Trips

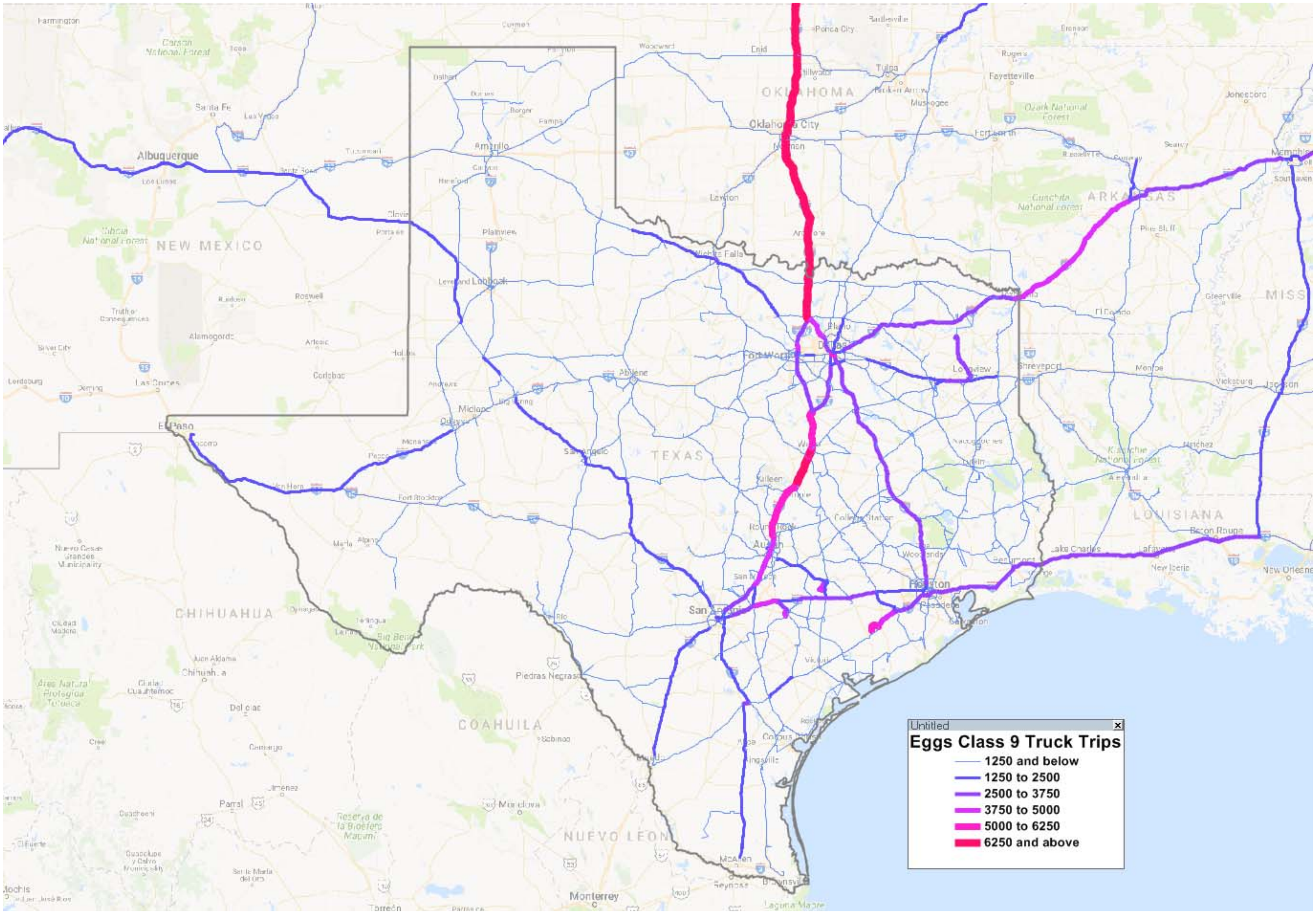

Figure 5.74: Eggs Class 9 Truck Trips

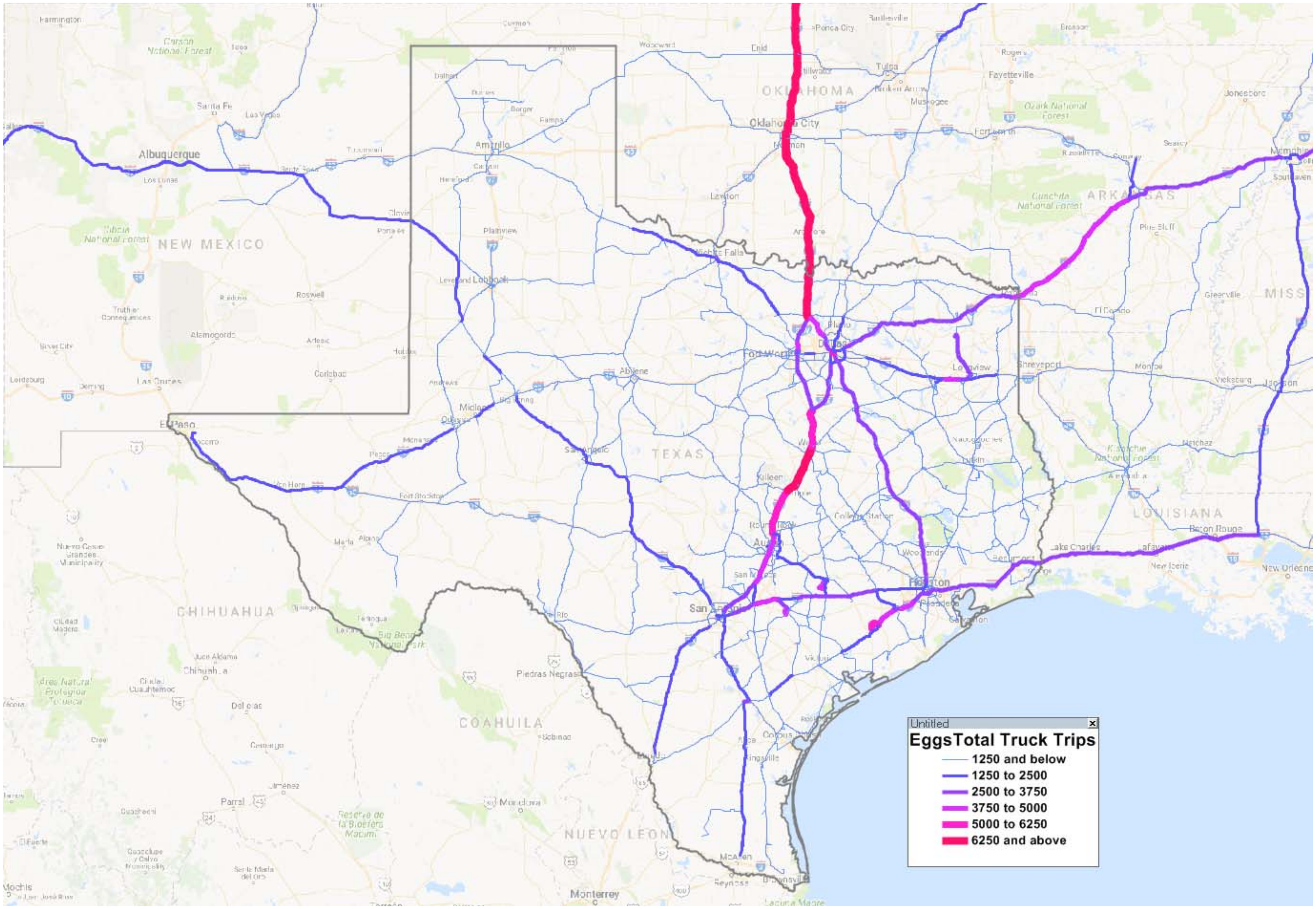

Figure 5.75: Eggs Total Truck Trips

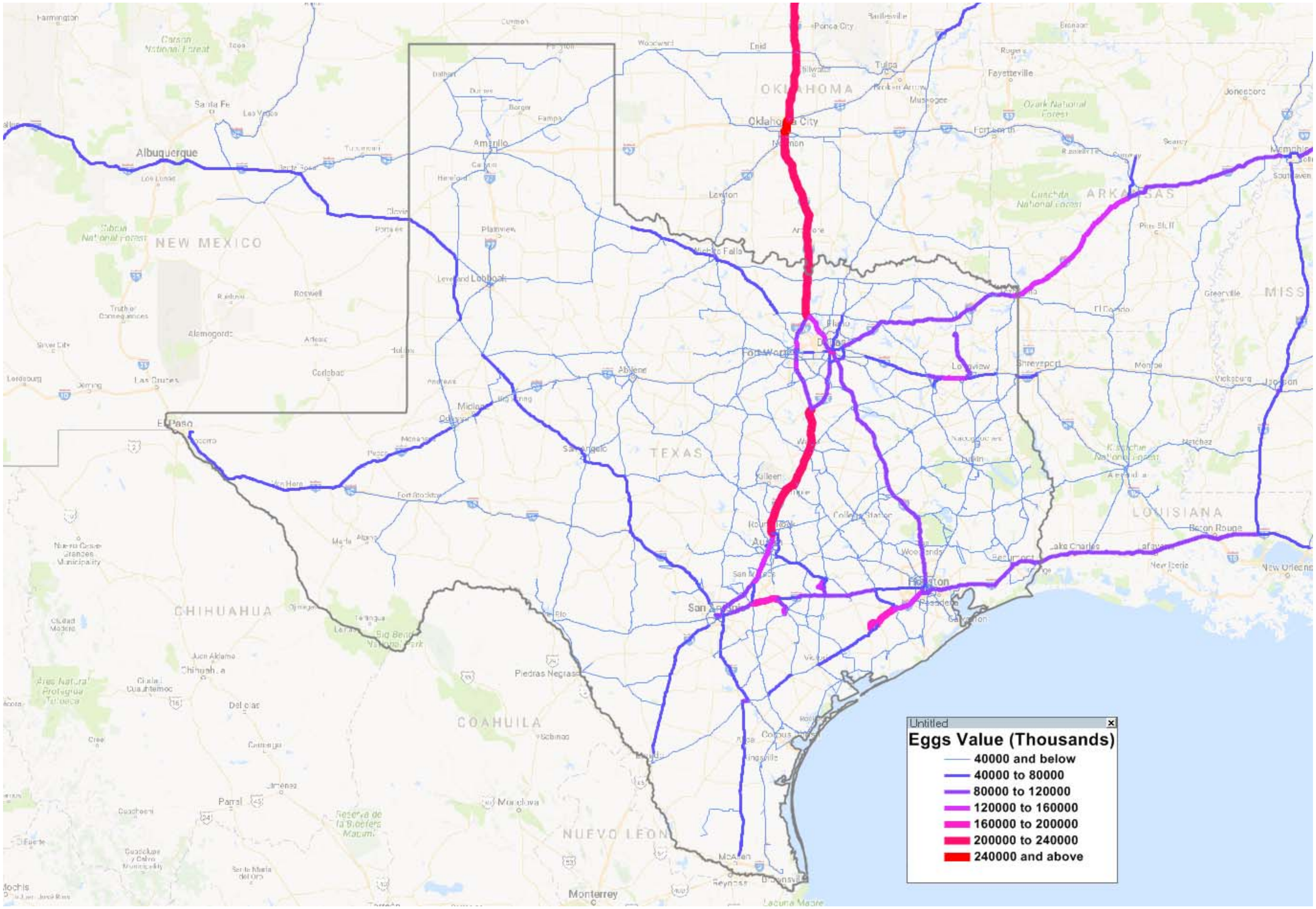

Figure 5.76: Eggs Value

5.4.7 Compare with Transearch Data

The Transearch data has a specific commodity category for poultry egg (STCC 01 52), though it is not clear if it contains only table egg. The research team processed the poultry egg data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.77.

The Transearch data supports the research team's finding (see Figure 5.75) that most egg trips originate in East Texas and are widely dispersed from there. The highways connecting big cities carry more egg truck trips. The total flows from Transearch and from our estimates in this project are similar. This is also the only case where a fair comparison between Transearch and this project can be drawn because the commodity types match well between these two sources.

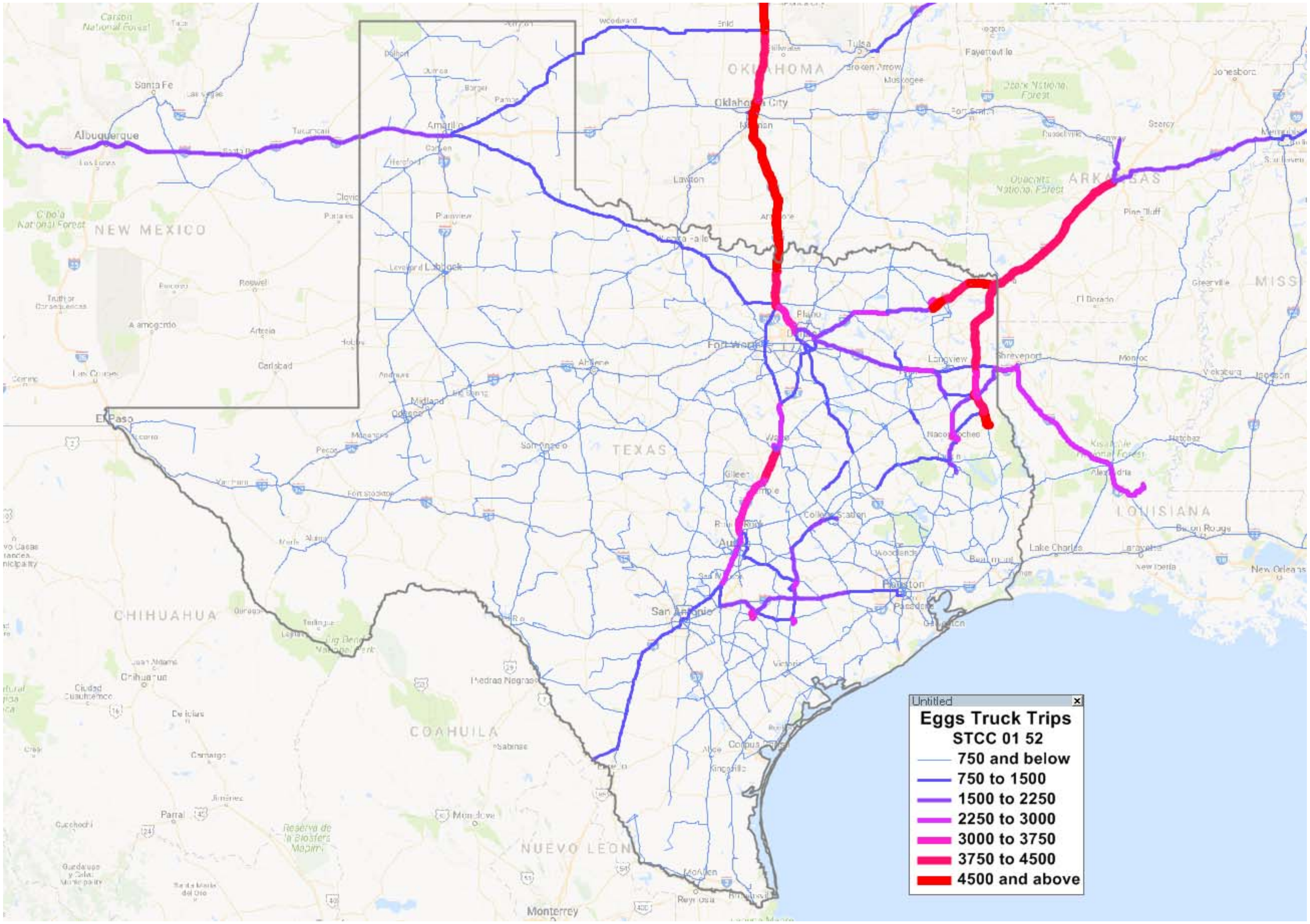

Figure 5.77: Transearch Egg Truck Trips

5.4.8 Seasonal Variation

The volume of eggs and broilers for meat production could significantly affect the transportation of them between farms, hatcheries, processing plants, and markets.

The research team read the report of Texas chicken and egg production and collected the data on Texas monthly egg production from the USDA database (USDA, 2017). Based on the collected data, the percentage of monthly egg production is then calculated. Figure 5.78 shows monthly egg production in Texas from 2015 to the beginning of 2017. All three years have very similar monthly patterns. The percentage of each month's production is in the range of 8 percent to 8.5 percent, with very slight changes from month to month. There is a noticeable decline in February that should result from fewer days in that month. No obvious seasonal variation for egg production in Texas was observed from the graph. The hypothesis test with X^2=2.09, which is far smaller than critical chi-square value ($X^2 = 2.09 < X_t^2 = 5.58$), confirms this observation.

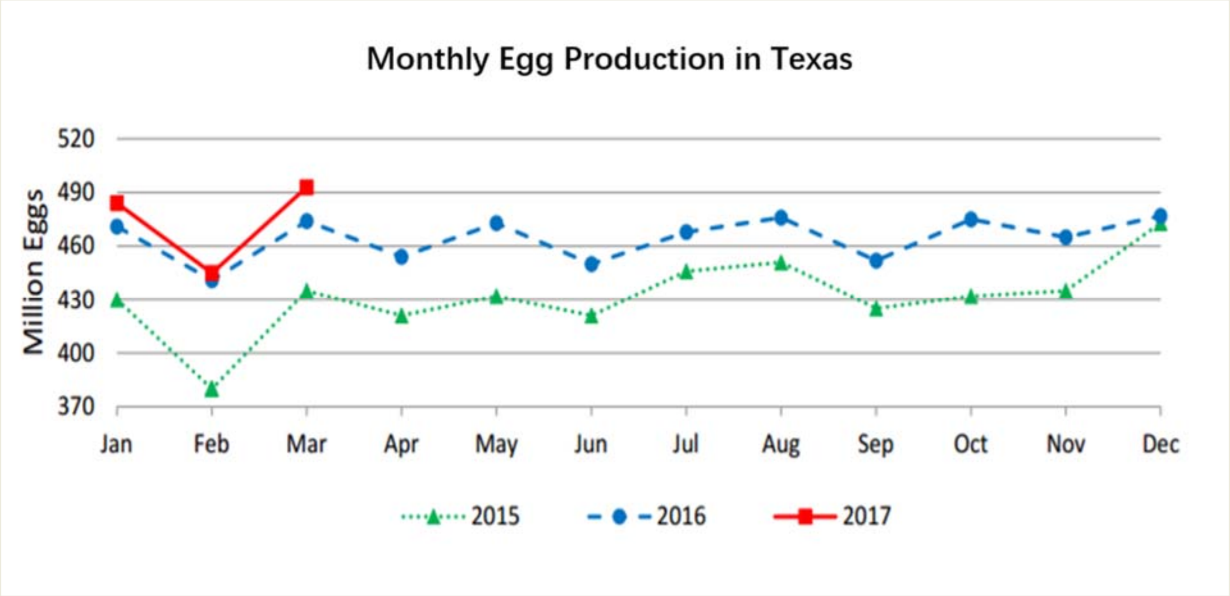

Figure 5.78: Run Sequence Plot of Monthly Egg Production in Texas

5.4.9 Daily Truck Trip Assignment

Similar to broilers, since no significant seasonal variation was observed on eggs' movement, it was assumed that the number of daily truck trips are the same for every month and the daily truck trip matrix was obtained by dividing the annual truck trip matrices by 295. The daily truck trips were then assigned to the network with the impact of congestion taken into consideration and the results are shown in Figure 5.79.

Similar to broilers, the original assignment performed in Section 5.4.6 did not include the flow from other states that passes through Texas. Note that the trip pattern for eggs shown in Figure 5.79 is not as concentrated on interstate highways in the Texas Triangle area[15], as the case without considering impact of travel time (see Figure 5.75). This proves that some trucks transporting eggs

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[15] The Texas Triangle is formed by the three main cities, Houston, Dallas, and San Antonio, connected by a highway system of Interstate 45, Interstate 10, and Interstate 35.

among those big cities in Texas will take alternative routes to avoid congestion on those primary freight routes, especially on interstate highways such as IH 35, IH 45, and IH 10.

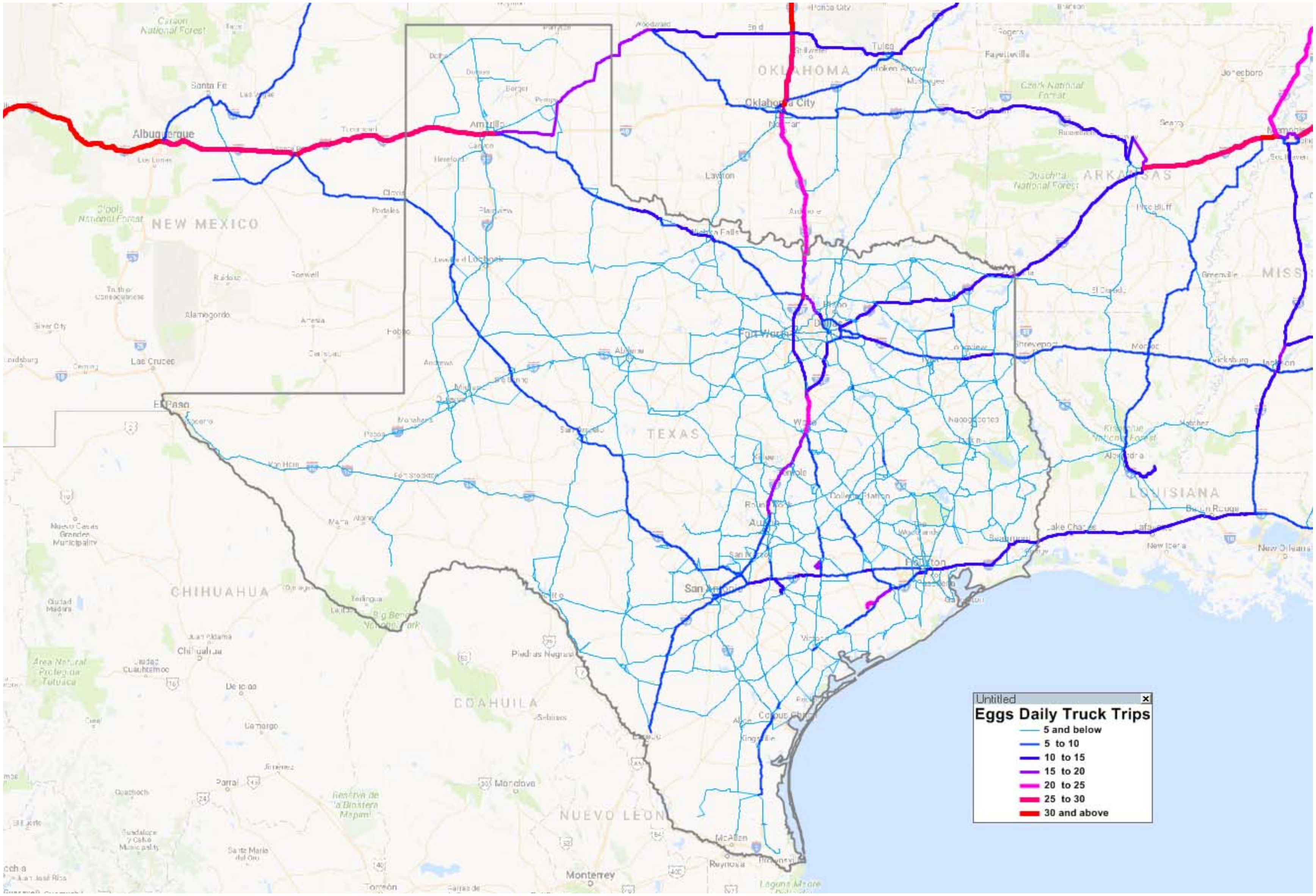


Figure 5.79: Eggs Daily Truck Trips

5.4.10 Summary

In 2015, Texas produced an estimated total of 4.5 billion table eggs. This is about 6% of US domestic production. However, due to its population and the large amount of eggs exported in Laredo and El Paso, Texas is a net importer of eggs from other states. Most of the eggs that are imported into Texas come from Iowa, Indiana, Ohio, Arkansas, or Nebraska. Most of the state exports from Texas go to California or Arizona.

The research team considered five egg companies in Texas for the development of OD matrices. These five companies have a total of 13 processing plants in Texas, although one did not produce any eggs in 2015. However, there are probably more companies and plants around the state that the research team did not consider.

Eggs are most likely transported using a Class 9 five-axle truck, though Class 6 three-axle trucks may also be used for shorter distance trips. The network analysis shows that interstate highways connecting big cities, such as IH 35 and IH 10, are major corridors for intrastate egg movements, especially the IH 35 section between Austin and Dallas-Fort Worth, which carries the highest value of eggs in Texas. Many egg trucks moving from Arkansas and Louisiana to California also pass through Texas along US 287 and IH 40.

Similar to broilers, no significant seasonal variation was observed with egg production, consumption, and shipment.

5.5 Timber

5.5.1 Background

Timber is essential to the Texas economy since the availability of timber is essential for paper production plants located in East Texas and the construction industry (especially residential construction). Total harvest removals in East Texas in 2014 were 544 million cubic feet (USDA Forest Service, 2016). The research team estimates that the majority of the timber harvested is estimated to have gone to either sawmills (34%), pulp and paper mills (49%) or plywood, veneer, and oriented strand board (OSB) mills (17%) (USDA Forest Service, 2012) (USDA Forest Service, 2016).

East Texas resources are of utmost importance to the Texas timber industry. In 2012, timberland in Texas occupied 14.2 million acres; 11.8 million acres in East Texas and 2.4 million acres outside of East Texas (Joshi et al., 2014). Due to the availability of data for East Texas timber compared to the rest of Texas, along with the fact that East Texas is responsible for the majority of timber harvesting, this analysis only considers the timber industry in East Texas. Also considered is the interaction between East Texas and neighboring states, namely western Louisiana, southwestern Arkansas, and southeastern Oklahoma.

There are six sub-industries to the forest sector (Joshi et al., 2014):

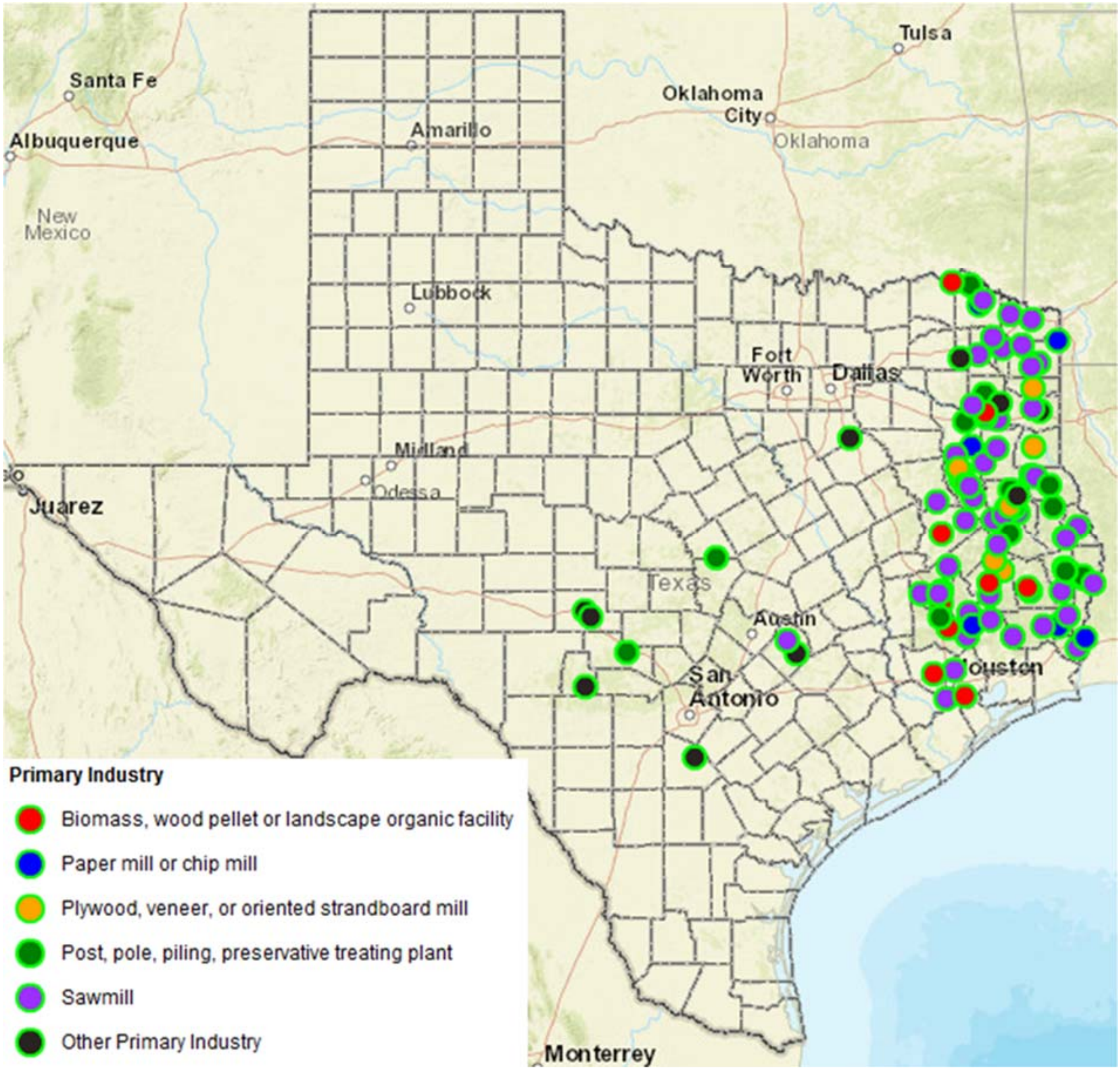
- Forestry (about 75% of Texas' production is in East Texas)
- Logging (about 75% in East Texas)
- Primary solid wood products (about 73% in East Texas)
- Secondary solid wood products
- Primary paper and paperboard products

- Secondary paper and paperboard products

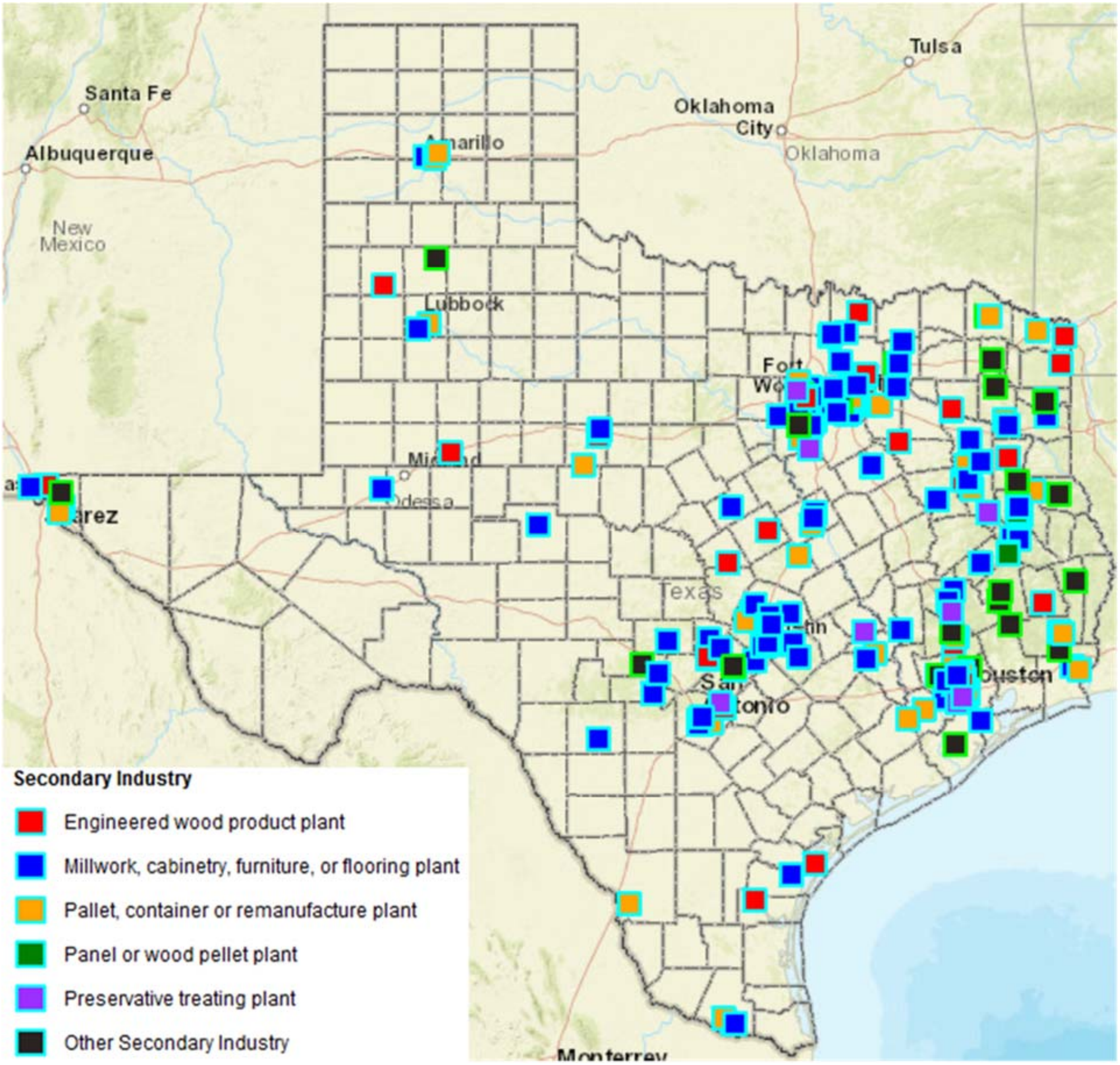
East Texas is most responsible for the output of four of the sub-industries: forestry, logging, primary solid wood products, and primary paper and paperboard products. After primary production, secondary products commonly leave East Texas and go elsewhere. Thus, the secondary solid wood and paper and paperboard sub-industries are not considered. For example, in Figure 5.80, provided by the Texas A&M Forest Service (2016), one can see the high density of primary plants in East Texas while secondary plants are dispersed throughout the state.

A second reason for why secondary sub-industries are not considered is because these sub-industries cause less damage to Texas' roads than the primary sub-industries—a truck carrying timber to a primary plant is generally heavier than a truck going to a secondary plant. According to the Texas A&M Forest Service (2016), Texas currently has 103 primary plants and 245 secondary plants. Given that only a portion of output from primary plants will even go to secondary plants, clearly the number of trips to secondary plants will be fewer and involve lighter trucks.

After timber is harvested in East Texas, it is usually taken directly to a mill for the desired product. Harvested timber need not stay in East Texas but it can also be taken to another mill in Louisiana, Arkansas, and Oklahoma. Likewise, timber harvested in these three states may be brought to an East Texas mill for processing. For this reason, the research team considers a total of 61 counties; 43 East Texas counties, nine western Louisiana counties, six southwest Arkansas counties, and three southeast Oklahoma counties. Mills of all sizes are taken into account for East Texas while only large mills are considered in the other three states.



a) Primary Industry



b) Secondary Industry

Figure 5.80: Locations of Primary Industry Plants and Secondary Industry Plants in Texas

Because it so widely used in construction, the demand for timber is greatly affected by the housing market. For example, because of the recession, timber harvest in Texas declined from 619 million cubic feet to 498 million cubic feet from 2007 to 2012 because construction slowed (Joshi et al., 2014). Along with that, timber demand can be difficult to model because of continual changes in recycling patterns (mainly paper and paperboard recycling) and demand for fuelwood (Howard, 2007). According to Howard (2007), the long-term outlook is that demand for most timber products will experience continued growth. However, the extent of that growth is hard to predict due the changes that can be caused by the domestic economy and imports (most notably from China). For this reason, the research team considers that most accurate predictions for timber harvesting can be found by studying data provided by the Forest Inventory and Analysis National Program for the most recent year available and adjusting for the current year by taking into account the changes in demand for construction, paper, and fuelwood; currently, the most recent data available is from 2014.

5.5.2 Supply Chain

As stated, after timber is harvested, it is taken to various mills for processing. The type of mill that the timber is taken to largely depends on the diameter of the tree. The general rule is that timber with a larger diameter at breast height will be taken to a sawmill while other timber can be taken to a paper mill, veneer mill, or another kind of mill. This first step (i.e., the transport of timber from the location of harvest to the primary mill) is what is modeled in this task. The primary mills considered are the following: 1) sawmills, 2) plywood, veneer, and OSB mills, and 3) paper mill and chip mills. The reason other mill types are not considered is because data shows that less than 1% of harvested timber will go to another mill type (USDA Forest Service, 2012).

After primary processing, the timber product is often ready to be sold to construction companies, warehouses (e.g., Home Depot), and other wholesalers/distributors. However, other times the timber product is taken to another mill for secondary processing. These secondary mills make higher quality products, such as furniture, high performance engineered wood, and cabinetry.

5.5.3 Datasets

In order to complete this analysis, the research team needed a few different types of data. First, we need timber harvesting by county to determine the “Productions” in a gravity model. Second, a list of mills and their locations was needed to determine the location of “Attractions” for the gravity model. In order to find the magnitude of the attractions, revenue data for each mill was collected. Lastly, in order to make the gravity model more accurate, information with regards to how much timber was imported and exported into Texas from each of the other states was needed.

Forest Inventory and Analysis National Program – Forest Inventory Data Online (FIDO)

The Forest Inventory and Analysis website provides a plethora of tools that can be used in the study of timber production. The most valuable of these is the FIDO tool, which provides spatial (at the state and county levels) and temporal (at the annual level) data for timber-related statistics. While FIDO provides data for every state, it does not provide harvesting data for each county. For Texas, only the 43 East Texas counties are available.

An example of some of the attributes that FIDO can report is shown in Figure 5.81, which is taken from the FIDO interface. Many of the attributes can be expanded to show even more specific categories. While most attributes can be used to study the availability of timber, and thus predict future harvesting volumes, the most important attributes that the research teams studied are listed under the “average annual harvest removals” category. These attributes are 1) trees harvested that are greater than or equal to 5” diameter, reported in cubic feet, and 2) saw timber removals, reported in board-feet. From these two attributes, the research team was able to estimate the approximate volume of saw timber and pole timber produced. The procedure for estimating the amount of saw timber and pole timber produced from these two attributes is explained in the Commodity Flow Estimation section.

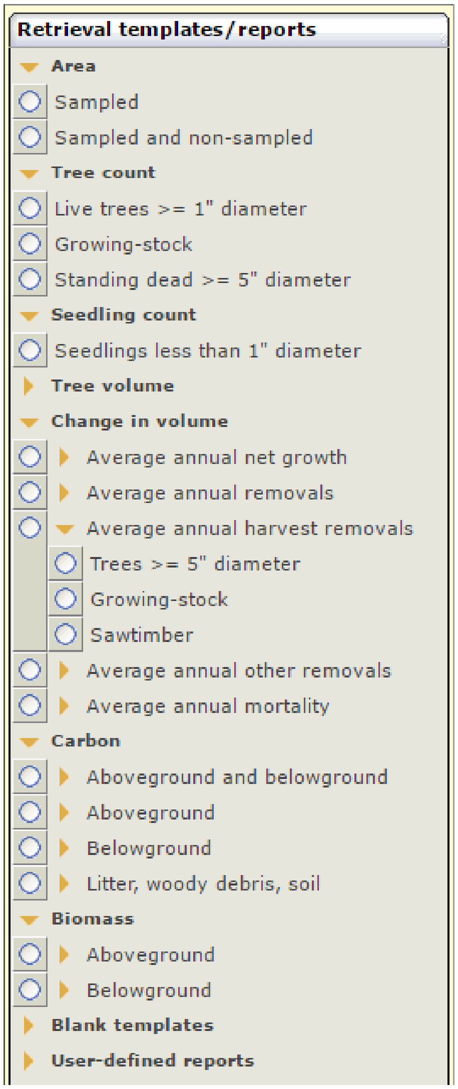


Figure 5.81: Types of Attributes FIDO Reports at the State (or County) Level

Texas A&M Directory of Forest Product Industries

This source was briefly mentioned earlier (see Figure 5.80) when discussing the locations of primary and secondary mills in Texas. This source was used to identify the names and locations of all sawmills; plywood, veneer, and OSB mills; and paper and chip mills in East Texas.

Another source, the Primary Forest Products Network (2016), was used to find mills as well. This second source was to verify that the Texas A&M Directory had not missed any important mills in East Texas. As both sources had identical lists, the research team was confident that all mills were accounted for. As opposed to the Texas A&M Directory, which supplies only information for the state of Texas, the Primary Forest Products Network contains information for the entire southeast US, as shown in Figure 5.82.

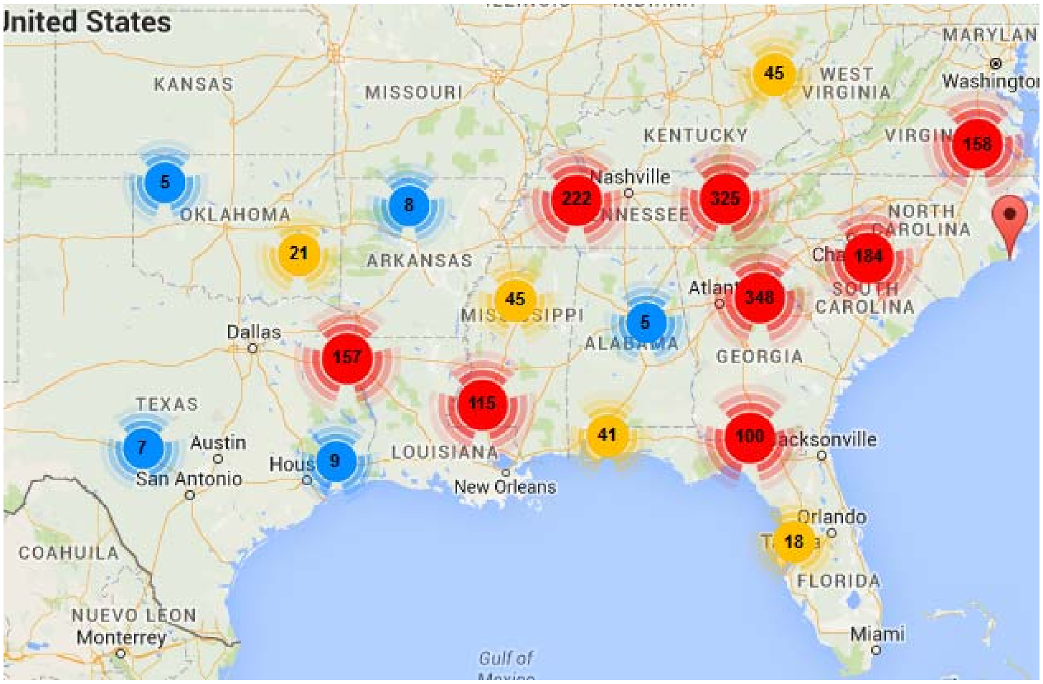


Figure 5.82: Locations of Various Mill Types

Socrates

While the Texas A&M Directory is successful in identifying the locations of attractions to be used in a gravity model, it is still necessary to determine the magnitudes of each of these locations. To do this, the research team searched for each of the mills found earlier or in the TWC's Socrates database. Here, the research team found ranges of revenues for the various mills. These revenues would be used to estimate attractions for each mill. Mills that were not found in the Socrates database were assumed to have the lowest revenue range ($1M–$5M) (if a company is not listed in the Socrates database, then it must be a small company).

Texas A&M Harvest Trends 2014 and USDA

The Texas A&M Harvest Trends (Edgar et al., 2014) provides the location of major mills in western Louisiana, southwestern Arkansas, and southeastern Oklahoma, as shown in Figure 5.83.

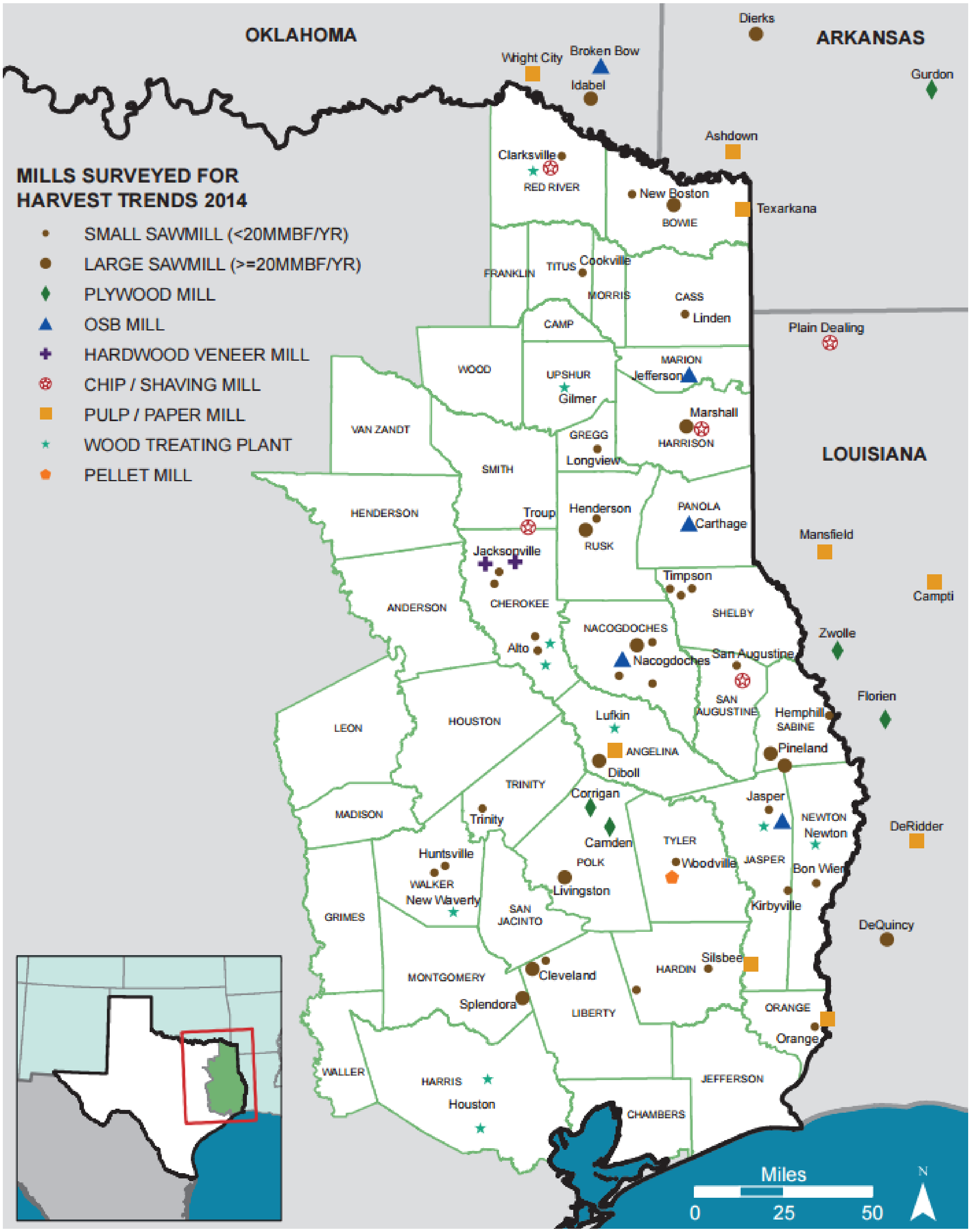


Figure 5.83: Locations of Various Mill Types in the Area Considered for Analysis

In this document, Edgar et al. (2014) also provide the volume of timber exported and imported to Louisiana, Arkansas, and Oklahoma in 2014. However, the specific amounts reported are an aggregate between the three states. In order to estimate imports and exports by state, the research team found documents presenting this information for 2009 (Brandeis et al., 2011a, 2011b, Johnson, 2011). The research team assumed that the proportions of imports and exports for 2014 will be the same as in 2009, allowing the team to estimate specific import and export amounts by state.

5.5.4 Commodity Flow Estimation

The commodity flow estimation began by extracting the annual average harvest removals for trees greater than 5 inches in diameter for all counties in Texas from FIDO for the year 2014. Since the total amount of timber in this category, 544 million cubic feet, was slightly greater than the 531 million cubic feet produced in Texas and flowing to mills identified by the Texas A&M Harvest Trends 2014 document, a reduction factor needed to be applied to all observations. Additionally, county-level data for the counties in question in Arkansas, Louisiana, and Oklahoma was also extracted from FIDO.

Once this data was obtained, an estimate of the amount of saw timber and pole timber needed to be calculated. Similar county-level data for saw timber was extracted from FIDO for all counties in question. Since this data was in board feet, a conversion was made to cubic feet using the International ¼-Inch Rule:

$$Sawtimber\ (cubic\ feet) = \frac{Sawtimber\ (board\ feet)}{12 * .65} \tag{5.4}$$

The 0.65 value in the denominator represents the amount of productivity realized from each cubic foot of saw timber. This value was estimated based on calculations using the International ¼-Inch Rule (Cassens, 2001). Once the conversion of saw timber to cubic feet was established, the amount of saw timber and pole timber for each county could be determined.

The percentage of saw timber and pole timber transported to each type of mill was determined using timber product output reports (USDA Forest Service, 2012). As expected, a large proportion of saw timber traveled to sawmills while a large proportion of pole timber traveled to pulp and paper mills. The portion of timber traveling to each type of mill was assumed to be constant for each county in Texas.

Exports and imports of timber were determined separately. The Texas A&M *Harvest Trends* 2014 document provided the total amount of timber imported and exported in the year 2014. The flow of timber was limited to the three states surrounding East Texas—Arkansas, Louisiana, and Oklahoma. For each of these states, the counties in close proximity to Texas with significant timber harvests were considered.

Production data was obtained from FIDO for the out-of-state counties and again converted to saw timber and pole timber estimates using the previously discussed methodology. The amount of timber imported into Texas from each state was estimated using previously published data from the USDA Forest Service Southern Research Station. Reports were obtained for Arkansas, Louisiana, and Oklahoma that indicated the amount of timber exported to each type of mill mentioned above. A summary of the amount of timber exported to each type of mill is shown in Table 5.17, separated by state. The amount of timber traveling to veneer mills or to any mills in Oklahoma is very limited.

Table 5.17: Timber exports out of Texas in cubic feet in 2014

	Sawmills	Veneer	Pulp	Total
Louisiana	15,983,428	4,740,000	35,666,768	56,390,196
Arkansas	3,135,640	-	33,386,019	36,521,659
Oklahoma	1,257,214	-	2,133,931	3,391,145
Total	20,376,282	4,740,000	71,186,718	96,303,000

Again using the figures published by Texas A&M Forest Service and the USDA Forest Service Southern Research Station, estimates for the amount of timber exported from Texas to out-of-state mills could be determined, as shown in Table 5.18. The out-of-state mills published in the Texas A&M Harvest Trends 2014 document were considered since these mills are all very large.

Table 5.18: Timber imports into Texas in cubic feet in 2014

	Sawmills	Veneer	Pulp	Total
Louisiana	2,765,945	3,931,320	18,776,319	25,473,584
Arkansas	-	-	21,253,991	21,253,991
Oklahoma	483,252	-	8,100,173	8,583,426
Total	3,249,197	3,931,320	48,130,483	55,311,000

The in-state primary mills reported in the Texas A&M Directory of Forest Product Industries were considered for this modeling effort. The revenue for each mill was estimated from the TWC's Socrates database. An estimate of the amount of timber received by each mill was estimated based on each mill's revenue relative to the total amount of combined revenue by mill type.

At this point, the total timber productions for each in-state county, broken down by mill type (sawmill, pulp/paper mill, or veneer/plywood/OSB mill) had been determined, as well as the amount of timber imported into the state from Arkansas, Louisiana and Oklahoma. The total timber attractions were also completed, using the mill revenue for each in-state mill and calculated exports.

In order to allocate the harvested timber to mills, three separate gravity models were calculated, one for each mill type. Road distance between each county, calculated using an algorithm in Python that used the optimal Google Maps route, was used for the friction factor in the gravity model.

Later, a Texas state statute was discovered that prohibits the transport of timber for more than 125 miles from the point of origin to the point of primary processing (the destination). Specifically, Sec. 622.041 reads:

> (a) A person may operate over a highway or road of this state a vehicle or combination of vehicles that is used exclusively for transporting poles, piling, or unrefined timber from the point of origin of the timber (the forest where the timber is felled) to a wood processing mill if:
>
> > (1) the vehicle, or combination of vehicles, is not longer than 90 feet, including the load; and

> **(2) the distance from the point of origin to the destination or delivery point does not exceed 125 miles.**
>
> (b) Subsection (a)(1) does not apply to a truck-tractor or truck-tractor combination transporting poles, piling, or unrefined timber.

Therefore, the team need to make sure that the gravity model used to create OD matrices reflects this statute. An adjustment had to be made so that all OD pairs that have a distance greater than 125 miles were adjusted to have an extremely high impedance value. This would prevent the majority of these prohibited trips from taking place. This was done for all three OD matrix types ([1] sawmills, [2] veneer, plywood, and OSB mills, and [3] pulp mills).

5.5.5 Transportation

Truck Type

A representative from Texas Logging Council was interviewed by the research team to provide the most pertinent information regarding truck types, weights, return trips, etc. The representative states that Class 8 trucks are used 98% of the time. The other 2% of the time Class 5 and 6 trucks are used; since the frequency of using Class 5 and 6 trucks is low, these two classes are not modeled.

Also, the Class 8 truck referenced here is not classified according to the FHWA Vehicle Classification list mentioned earlier, but according to the GVWR schedule—meaning that Class 8 timber trucks weigh more than 33,000 lbs. Still, most of the time these Class 8 trucks (according to the GVWR) have a single trailer and five axles, and thus correspond to a Class 9 truck according to the FHWA Vehicle Classification standard, as was shown in Figure 5.55.

However, unlike the truck that Figure 5.55 depicts, the trailer is not enclosed. Usually two different types of trailers are used—a pole trailer and a four-bolster set out trailer. Each of these two trailers are used roughly 50% of the time between the three mill types that were investigated ([1] sawmills, [2] veneer, oriented strand board (OSB), and plywood mills, and [3] paper mills). A truck and pole trailer, shown in Figure 5.84, will usually have a tare weight of around 27,000 lbs and will carry a net weight of timber of about 28 tons. On the other hand, a four-bolster set out trailer, shown in Figure 5.85 (Bolding et al., 2005), will usually have a tare weight of about 30,000 lbs and will carry a net weight of timber of 25 tons. Since these two trailer types are very similar in total weight (tare weight and net weight of timber), the research team did not differentiate between the two and assumed a net weight of timber loaded on a truck to be 27 tons. This is a parameter that may be changed inside the model.

Figure 5.84: Class 8 (GVWR) or Class 9 (FHWA Vehicle Classification) Five-axle Truck with a Pole Trailer

Figure 5.85: Class 8 (GVWR) or Class 9 (FHWA Vehicle Classification) Five-axle Truck with a Four-bolster Trailer

Truck Capacity

As mentioned in the previous section, the research team estimated three county-to-county OD matrices (one for each of the following: [1] sawmills, [2] veneer, plywood, and OSB mills, and [3] pulp mills). These OD matrices were reported in cubic feet. However, the information that is available regarding truck capacity is in tons (assumed to be 27 tons as stated earlier). Thus, in order to know truck capacity in cubic feet, one must know the density of the East Texas timber in order to convert from a volume to a weight.

This is problematic because most sources report the density of timber when it is dry. However, the timber, after it is cut down, is still wet and can weigh as much as two times its dry weight (Wood Database, 2016). Thus, rather than using a density of timber reported when it has dried, the research team divided the total weight produced by East Texas in 2014 (roughly 20 million tons) (Edgar et al., 2014) by the total volume harvested in 2014 (roughly 531 million cubic feet), which was modeled in the previous section. This yielded an average density of about 75 lbs/cubic foot. This value was used to determine that the average timber truck in East Texas carries about 720 cubic feet. With that said, the average density of timber is used as an input to the model to allow for updates if new parameters are used.

Converting Tonnage to Equivalent Trucks

Each truck holds on average a net timber weight of 27 tons. Using a density of 75 lbs/cubic foot means that on average each truck will hold 720 cubic feet. Thus, the updated OD matrices are divided by 720 to get the number of loaded trucks going from each origin to each destination.

Estimating Empty Trucks

According to the representative from Texas Forestry, 99.9% of the time, trucks return empty to the forests. The only exception to this rule is if timber is rejected from a mill and the mill loads the timber back on to the trucks in order to get them out of the plant. Thus, for all trips modeled to deliver timber, there will be another empty trip in the opposite direction.

Results

Full results, which show the number of truck trips from county to county for the 43 East Texas counties (along with 9 Louisiana counties, 6 Arkansas counties, and 3 Oklahoma counties for a total of 61 counties), are included in Appendix 1 of this report. Results of the model are available based on what type of mill the timber is going to. Aggregate results, regardless of mill type, are also available. Tables 5.19 and 5.20 provide a brief summary for Texas. Please note that these results are heavily dependent on the average timber density; thus, if more accurate timber densities are found, the model should be updated.

Table 5.19: Total number of loaded Class 8 truck trips (by GVWR weight classes) for 2014 for the top five counties that (a) receive timber for processing and (b) send timber from forests, rounded to the nearest hundred

Jasper County, Texas	180,400
Cass County, Texas	172,500
Polk County, Texas	79,300
Orange County, Texas	63,800
Sabine County	56,100

(a)

Polk County, Texas	48,500
Newton County, Texas	45,800
Harrison County, Texas	42,000
Cass County, Texas	41,900
Tyler County, Texas	41,500

(b)

Table 5.20: Total number of loaded Class 8 truck trips (by GVWR weight classes) modeled for 2014 for the top ten[16] OD combinations, rounded to the nearest hundred

Origin	Destination	Loaded Truck Trips	% of Total Trips
Jasper County, Texas	Jasper County, Texas	24,400	2.8%
Cass County, Texas	Cass County, Texas	23,100	2.7%
Newton County, Texas	Jasper County, Texas	17,200	2.0%
Tyler County, Texas	Jasper County, Texas	15,700	1.8%
Polk County, Texas	Jasper County, Texas	14,200	1.6%
Harrison County, Texas	Cass County, Texas	13,400	1.5%
Panola County, Texas	Cass County, Texas	13,200	1.5%
Walker County, Texas	Jasper County, Texas	12,900	1.5%
Anderson County, Texas	San Augustine County, Texas	12,600	1.4%
Rusk County, Texas	Cass County, Texas	12,200	1.4%

5.5.6 Network Analysis

The truck trip matrix for timber was recalculated to allocate truck trips from out-of-state counties in Louisiana, Arkansas, and Oklahoma to border centroids. As anticipated, truck trips for timber are concentrated in East Texas, as seen in Figure 5.86. Flow is rather localized, since a gravity model was utilized to allocate timber from a forest to its nearest primary mill. It is important to note that some state and US highways in East Texas may see more than 150,000 timber truck trips per year based on these estimates.

The average price of timber was estimated using 2015 annual price trends in the state of Texas from the Texas A&M Forest Service. Three separate OD matrices had previously been estimated based on the type of wood and the destination mill of each type of wood. These separate matrices were used to determine the total value of timber truck shipments. The average value of sawlogs was estimated at $33.1717 per ton, while pulpwood and veneer logs were estimated at $9.4079 per ton (Texas A&M Forest Service, 2016). The value assignment for timber can be seen in Figure 5.87 (in thousands). Timber is a high-weight, low-value commodity, especially at the forest-to-mill stage of the supply chain. Despite the large number of truck trips estimated, most links in the Texas primary and secondary freight networks carry relatively little total value of timber. Few links carry more than $60 million of raw timber per year.

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[16] These top ten OD combinations only combine for about 18% of the loaded truck trips. The top 52 OD combinations combine for about 50% of all loaded truck trips.

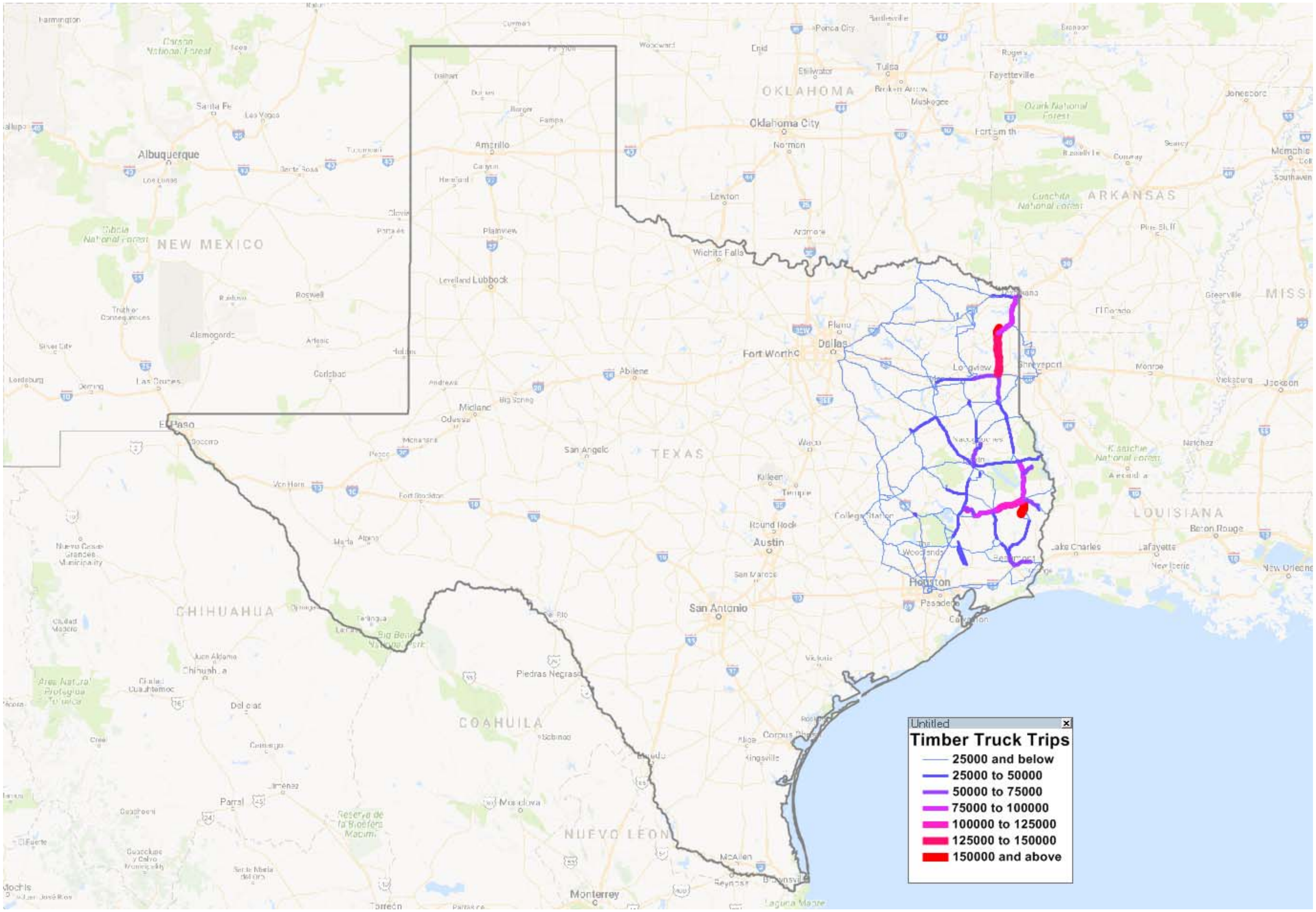


Figure 5.86: Timber Truck Trips

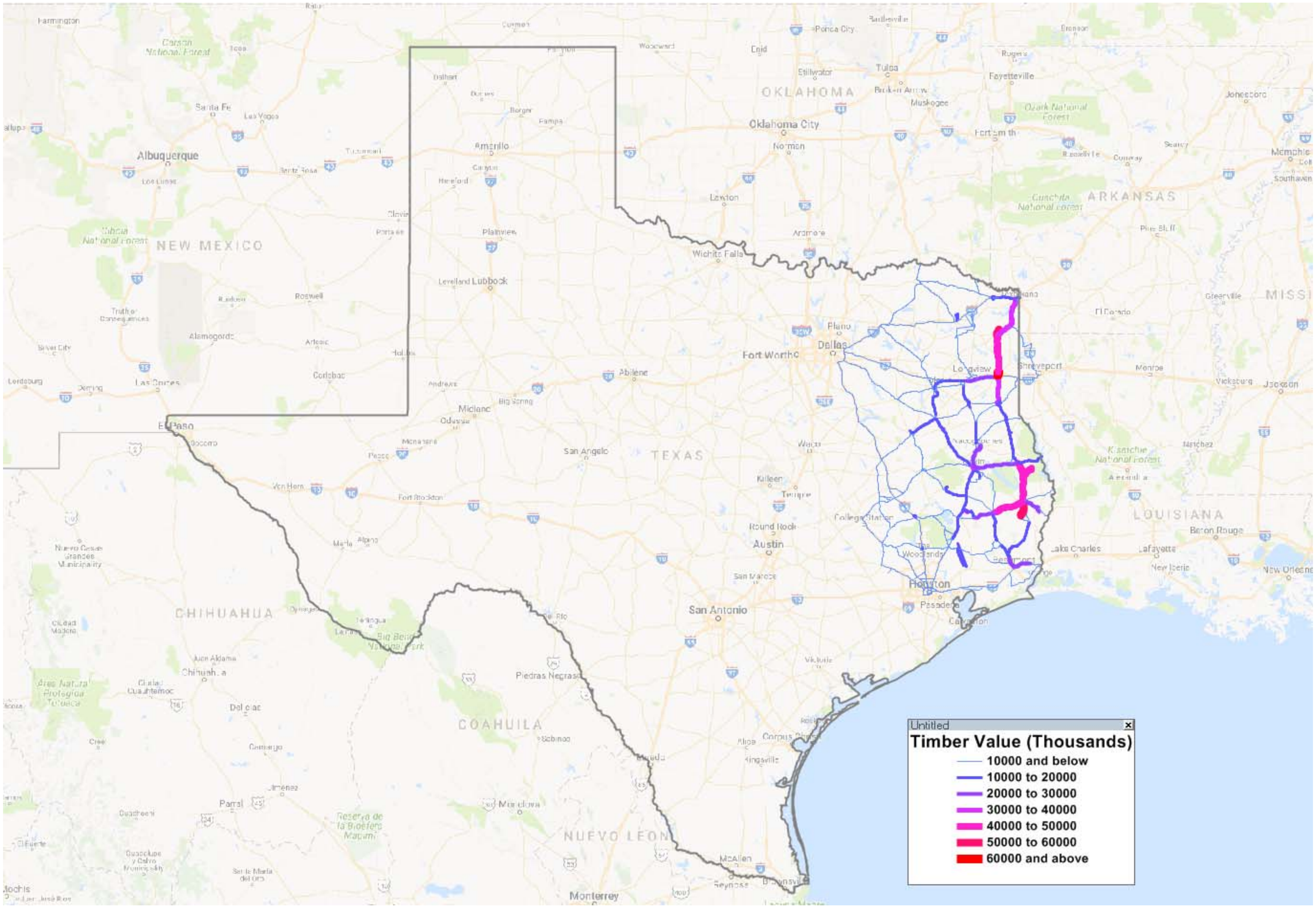


Figure 5.87: Timber Value

5.5.7 Compare with Transearch Data

As shown in Table 4.1, the closest commodity category to Timber in the Transearch database is primary forest materials (STCC 24 11). The research team processed the primary forest materials data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.88.

Transearch data shows very large primary forest materials truck flows starting from Louisiana. Higher flows are shown in the east Texas area. IH 20 between the Texas-Louisiana border and Dallas is an important corridor for moving primary forest materials. This project focused on timber exports from east Texas. While the truck flow patterns differ, both the Transearch database and this project estimate a high number of trucks in the east Texas network.

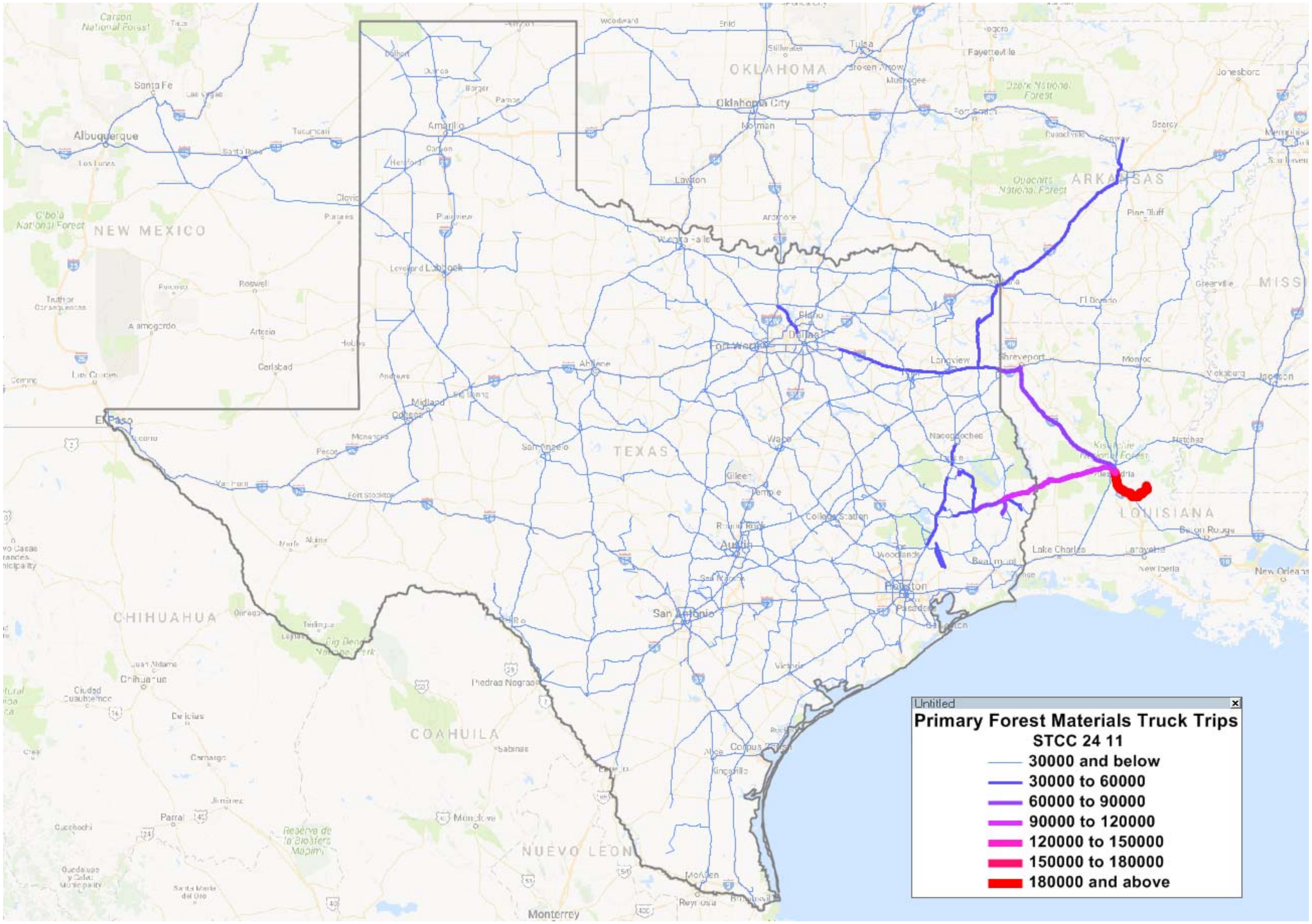


Figure 5.88: Transearch Primary Forest Materials Truck Trip

5.5.8 Seasonal Variation

No obvious seasonal variation was observed associated with timber production or transportation during the research team's study of timber in Texas. No monthly data about timber production or consumption in Texas was found either. Therefore, the research team assumed no significant seasonal variation for Timber movement.

5.5.9 Daily Truck Trip Assignment

Similar to broilers and eggs, since no significant seasonal variation was observed on timber's movement, it was assumed that the number of daily truck trips are the same for every month and the daily truck trip matrix was obtained by dividing the annual truck trip matrices by 295. The daily truck trips were then assigned to the network with the impact of congestion taken into consideration and the results are shown in Figure 5.89.

The overall flow pattern for timber shown in Figure 5.89 is very similar to the results obtained in the original traffic assignment when the impact of congestion was not considered (see Figure 5.86). Congestion does not have significant impact on the flow pattern of timber mainly because the timber flows modeled in this project are concentrated in the east side of the state and most are local short-distance trips.

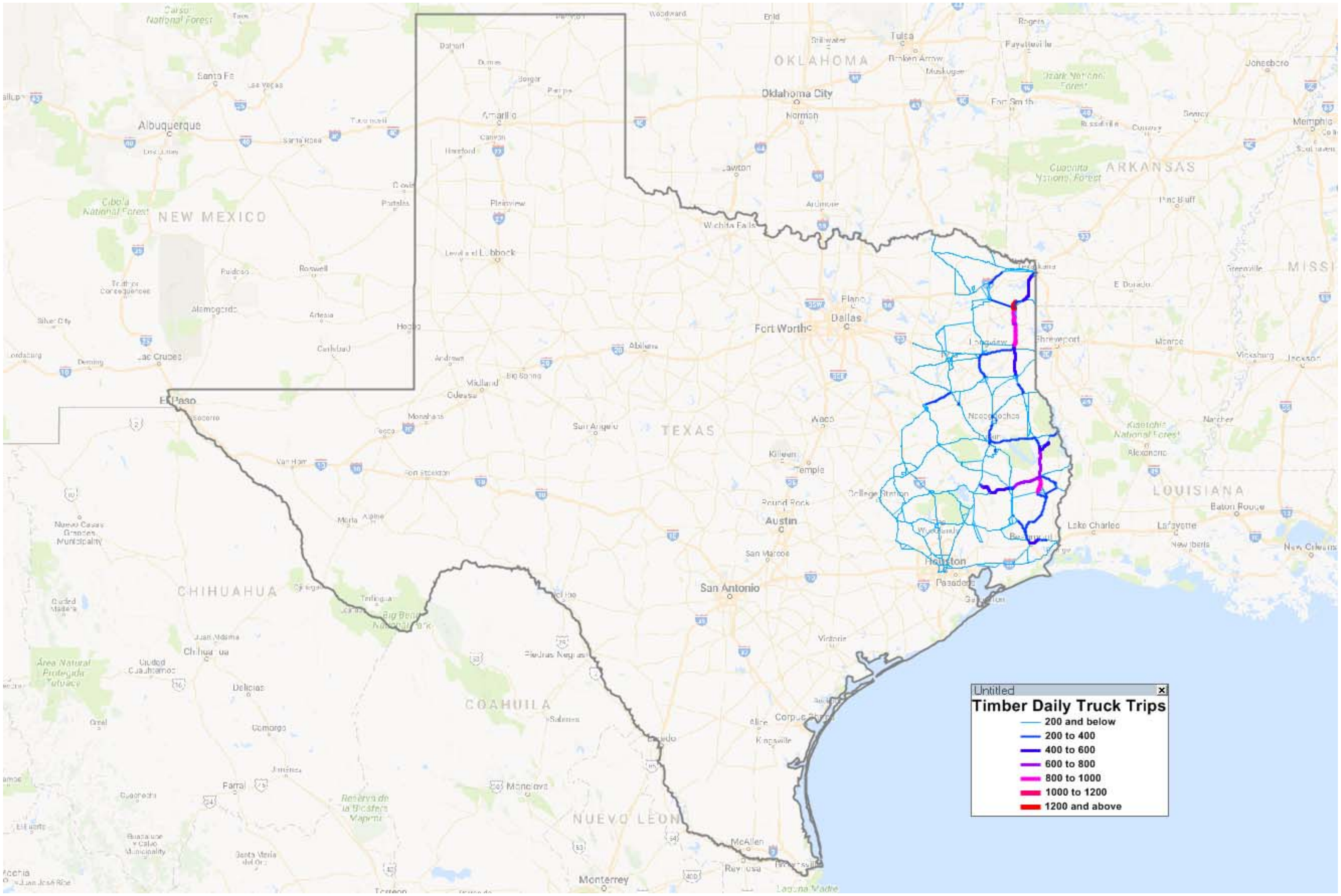


Figure 5.89: Timber Daily Truck Trips

5.5.10 Summary

Timber is a vital commodity due to the industries it supports, namely construction and paper. In this analysis the research team considered the part of the supply chain that deals with transporting timber from harvest to the primary mill. Using production data from FIDO and attraction data based on mill revenue from Socrates, the research team used a gravity model to determine OD flows.

As expected, the flow of timber is limited to the East Texas region, where most of the timber production and mills are located. There are significant interstate movements between Texas and the surrounding states of Arkansas, Louisiana, and Oklahoma. The model separated timber based on the type of destination mill, producing three separate OD matrices (units in cubic feet of timber).

Seasonal variations were not observed associated with timber production, consumption, or shipment. The impacts of congestion on timber movements are limited, as they are primarily moved on short local roadways in east Texas.

5.6 Gasoline and Fuel Ethanol

5.6.1 Background

While Texas is rightly thought of as an oil producing and refining state, a great deal of gasoline consumption also occurs here. Most movements occur via pipeline or rail to make finished gasoline at fuel terminals, but a significant amount of trucking along Texas's roadway network occurs to move the finished gasoline to over a thousand fuel stations around the state.

According to the *Ethanol Producer* magazine, there are 216 ethanol plants across the country. Only four of these are located in Texas, although one in New Mexico is very close to the border. The US has a total ethanol production capacity of 15,700 million gallons annually (Figure 5.90), while Texas's four facilities have a capacity of only 280 million gallons annually (Ethanol Producer Magazine, 2016). It is worth noting that, while Texas contains less than 2% of total US ethanol plants, it contains nearly 17% of ethanol facilities that accept sorghum. According to the EIA, Texas consumes 1155 million gallons of ethanol annually, meaning that much is imported from the Midwest (US EIA, 2013).

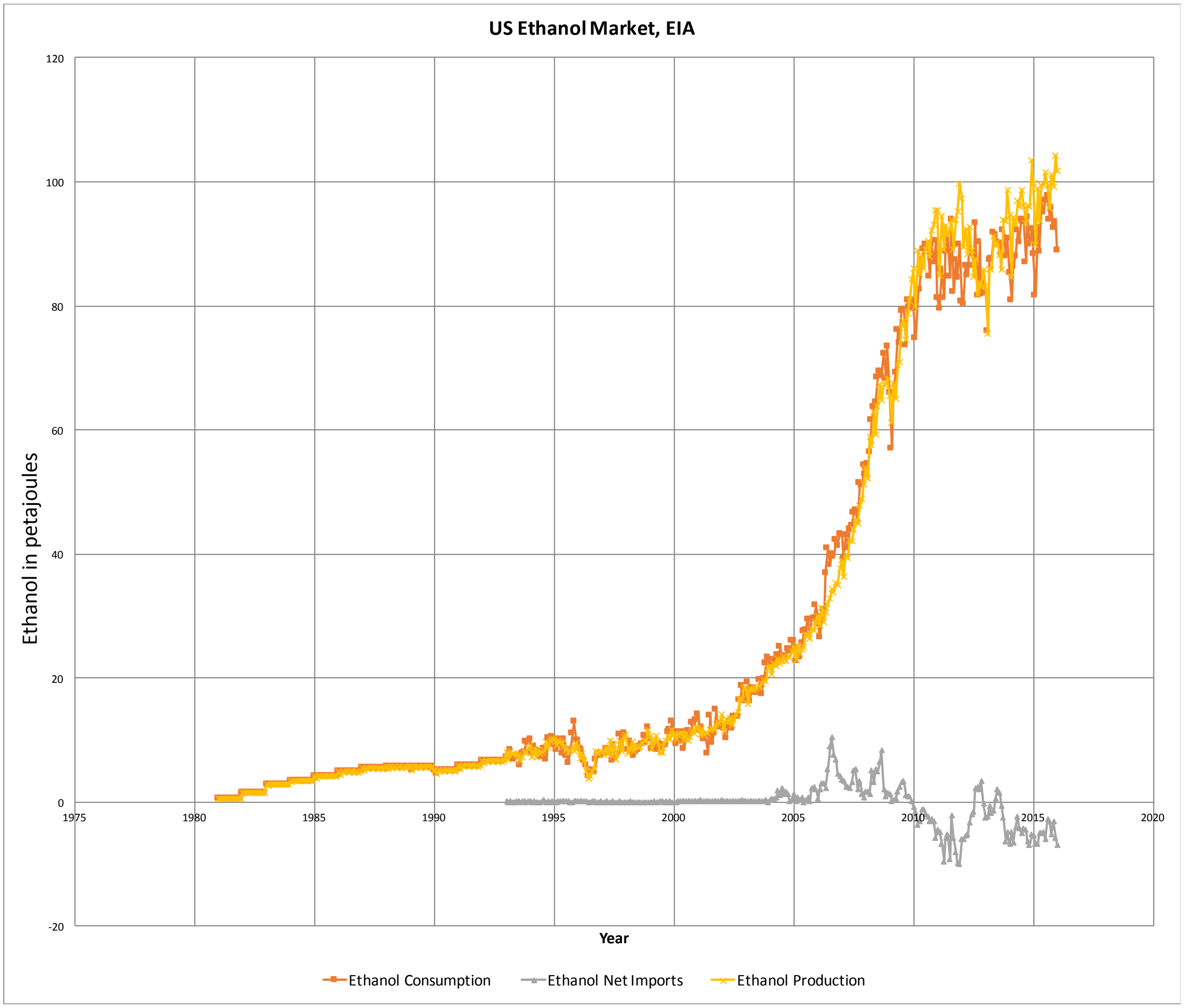


Figure 5.90: US Ethanol Production and Consumption (EIA)

5.6.2 Supply Chain

Figure 5.91 illustrates the gasoline supply chain. The primary product is produced at petroleum refineries and shipped via pipelines to 116 fuel terminals around the state. Before being trucked from the terminal to local natural gas stations, the gasoline is blended with 15% ethanol and small quantities of fuel additives. The ethanol is provided by train directly to the fuel terminal, while the additives are normally trucked in.

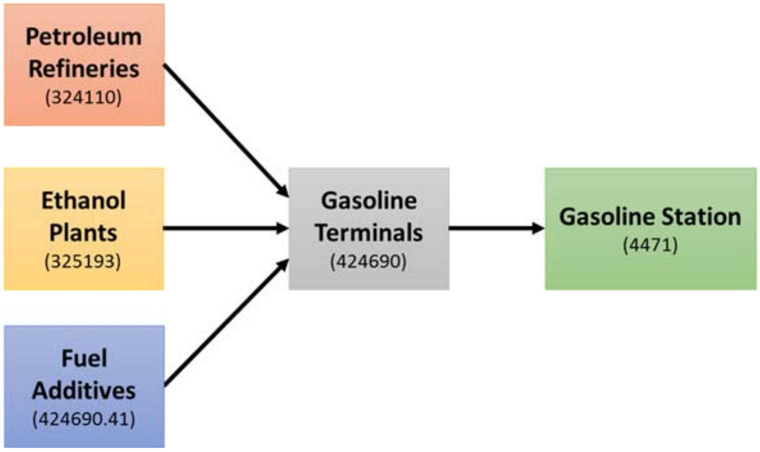


Figure 5.91: Gasoline Supply Chain

The ethanol supply chain begins at farms where the grains are grown. Primarily two grains are used in the United States: corn and sorghum. For ethanol production in Texas, corn is typically shipped by rail from the Midwest, while sorghum is shipped from local Texas farms via truck. Because only the grain's starch is converted to ethanol at the production facility, there is a substantial amount of byproducts produced, called distillers grains that are high in protein and lipids. These distillers grains are classified as either wet or dry based on their moisture content. Dry distillers grains last much longer without rotting, and are thus suitable for long-distance shipment, but the drying process requires additional energy inputs. Wet distillers grains are only viable for less than a week, so they are suitable when there is a large demand for livestock feed relatively close to the plant, as is the case for all of West Texas's ethanol plants. Figure 5.92 illustrates this supply chain along with the NAICS commodity codes. The commodity flow modeling focuses on the link between the sorghum farms and the ethanol plants.

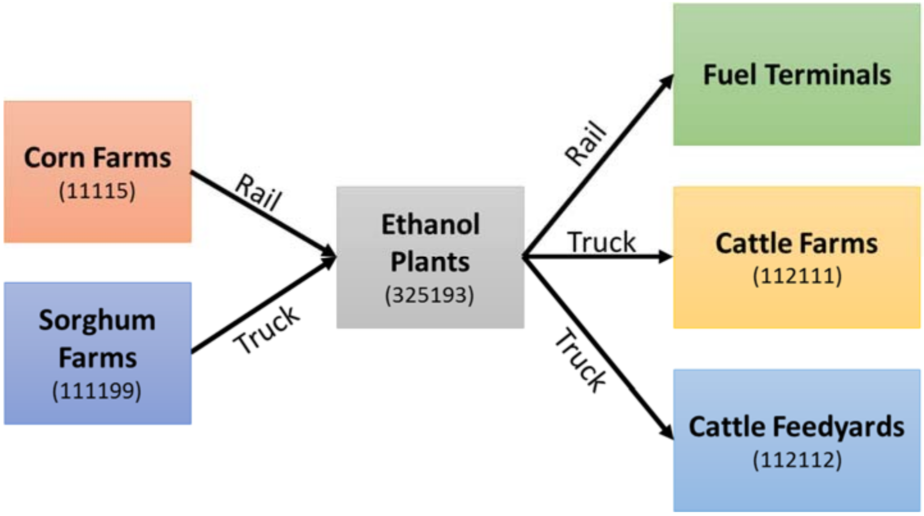


Figure 5.92: Ethanol Supply Chain

One bushel of corn, which has a mass of 25.4 kg (56 lbs. weight), produces roughly 7.7 kg of livestock feed (17 lbs.) and 10.6 L (2.8 gallons) of ethanol (Iowa Corn Growers Association, 2016). Sorghum bushels have similar levels of output.

Ethanol is mixed with gasoline at fuel terminals before being shipped to gas stations around the state. The typical mixture is 15%, which is the highest percentage that a non-modified internal combustion engine calibrated for gasoline can safely handle. The gasoline section of this report has more information on fuel terminals.

As noted, some of the waste products from the ethanol production facilities are suitable as livestock feed for ranches. These products, usually wet distillers grain with solubles (WDGS), are primarily moved by truck. Because the food left over from the ethanol production process is high in protein and lipids, WDGS is very valuable as livestock feed.

5.6.3 Datasets

The Energy Information Administration (EIA) has data on annual motor gasoline consumption by state. The most recent year that data is available for is 2014. Texas consumed 311.5 million barrels (37.14 million cubic meters) of gasoline for the purpose of transportation in 2014 (US Energy Information Administration, 2014).

Oil Refineries

Crude oil is processed to gasoline and other products at oil refineries. Because the US uses relatively more gasoline than other petroleum products, US refineries are tooled to produce larger fractions of gasoline from their crude oil inputs. Many of America’s refineries are in Texas, and the crude oil is brought-in either via pipelines (see Figure 5.93) or large tanker vessels. The raw gasoline is shipped from oil refineries to gasoline storage terminals mostly by pipeline.

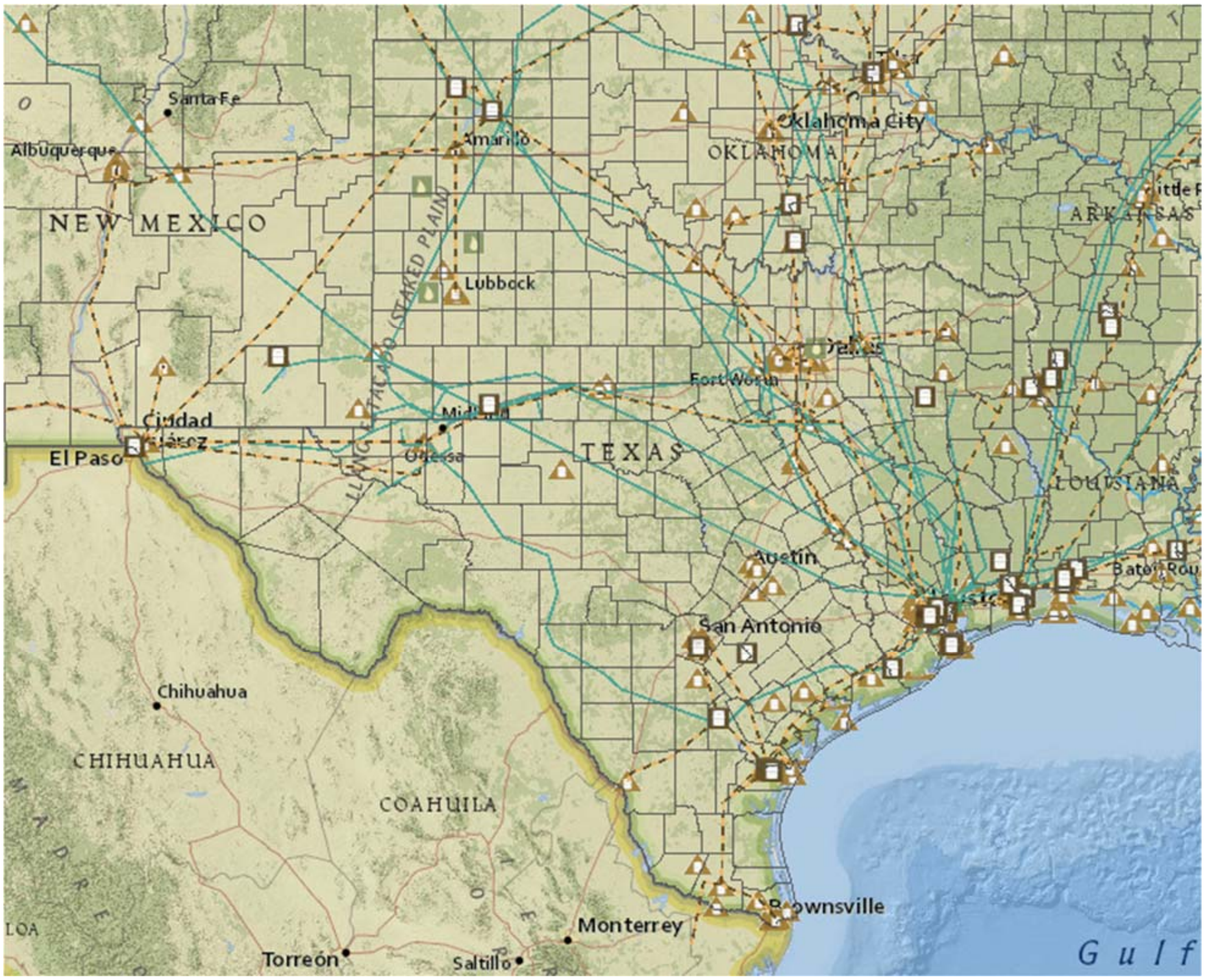


Figure 5.93: Pipelines across Texas

Fuel Terminals

The raw gasoline from refineries is blended with ethanol and other additives at fuel terminals and stored for shipment via truck to gas stations. Very little is shipped to fuel terminals via truck, other than the small quantities of fuel additives; ethanol and gasoline arrive by train and pipeline respectively. This means that fuel terminals typically have nearby rail, pipeline, and highway access. Figure 5.94 shows a fuel terminal in Waco. There is a rail line with a spur for unloading ethanol on the eastern side of the terminal, a pipeline coming from the northeast, and a local highway at the western edge.

Figure 5.94: Fuel Terminal in Waco

The research team distributed the quantity of gasoline evenly across fuel terminals in Texas to generate production figures. Information about the location of fuel terminals came from the IRS, which has a database of all US fuel terminals, including 116 in Texas (Figure 5.95). Most of the terminals are closely spaced together in large cities, or they are located near refineries. Attractions came from a weighted distribution at the zip code of 2007 gas station revenue data from the Economic Census (US Census Bueau, 2007).

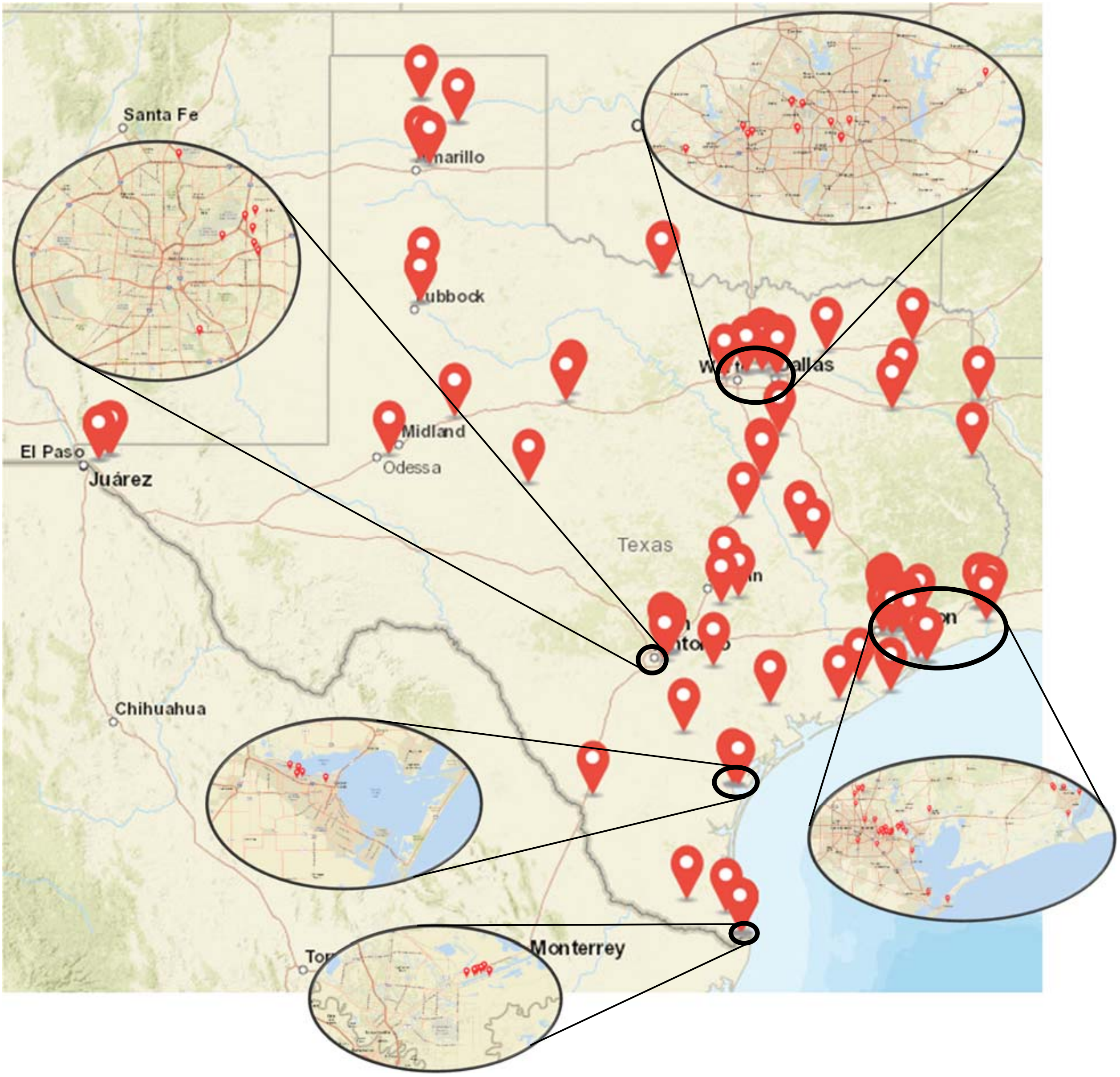
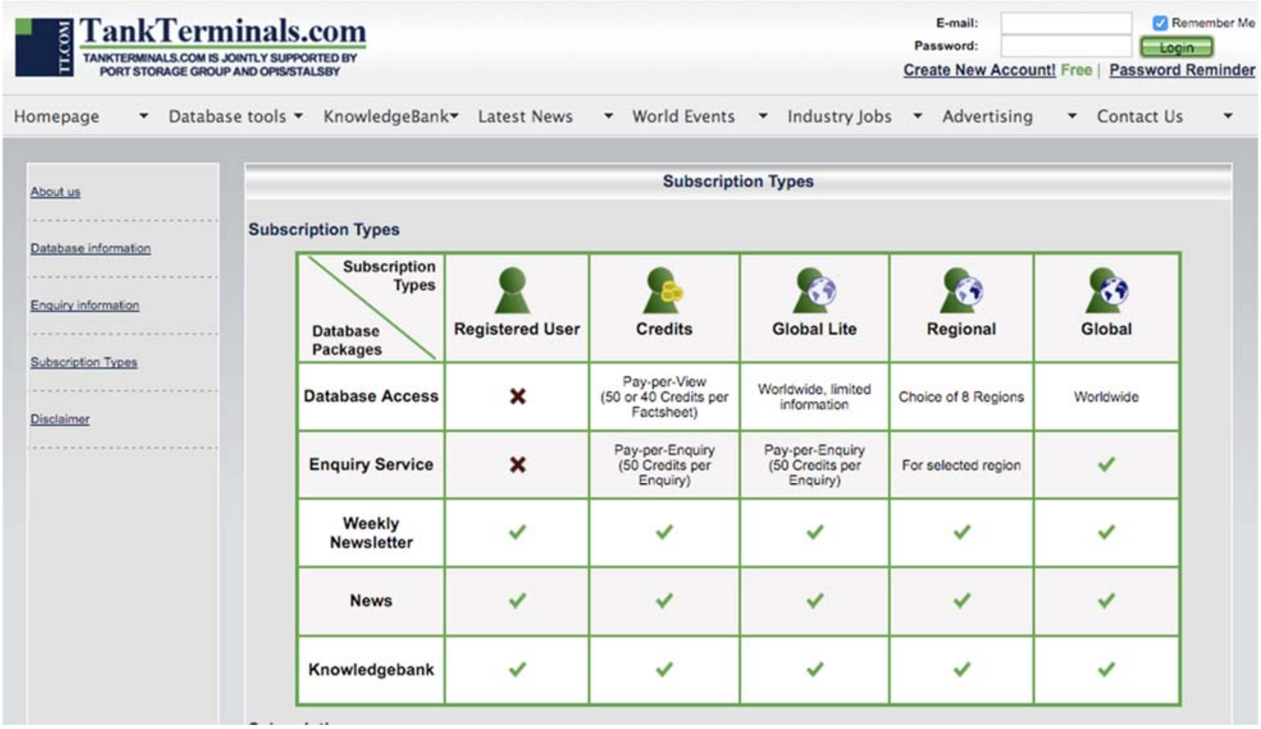


Figure 5.95: Texas Fuel Terminals

TankTerminals.com has information about petroleum storage terminals around the world, including Texas (Port Storage Group and OPIS/STALSBY, 2014). This information includes the capacity of each storage facility, which is a crucial missing element in the current gasoline distribution model (Figure 5.96).



Subscription Types

Subscription Types

Subscription Types / Database Packages	Registered User	Credits	Global Lite	Regional	Global
Database Access	✗	Pay-per-View (50 or 40 Credits per Factsheet)	Worldwide, limited information	Choice of 8 Regions	Worldwide
Enquiry Service	✗	Pay-per-Enquiry (50 Credits per Enquiry)	Pay-per-Enquiry (50 Credits per Enquiry)	For selected region	✓
Weekly Newsletter	✓	✓	✓	✓	✓
News	✓	✓	✓	✓	✓
Knowledgebank	✓	✓	✓	✓	✓

Figure 5.96: Tank Terminals Data Options

Ethanol Production Facilities

Ethanol is produced from bio matter. Nearly all ethanol plants in the US use corn, while a few use sorghum. Texas has some ethanol production, which is described in another section, but most of the ethanol consumed in Texas is shipped from the Midwest via trains.

Additives Manufacturing

Fuel additives are what distinguish different gas station brands, and, to some extent, premium versus regular gasoline. Additives, aside from ethanol, are blended in small enough quantities that they can be trucked to the fuel terminals from their production facilities. The research team has not found much information on these additives, but they could contribute to significant amounts of truck trips.

Gas Stations

The Economic Census has information on gas station revenues. This was assumed to correlate to gas station petrol receipts, so the total statewide gasoline consumption (known from the EIA) was apportioned to zip codes based on the relative amount of gas station revenue in each zip code.

Figure 5.97 shows the relative production of Texas's four ethanol production facilities (two in Hereford, and one each in Plainview and Levelland, as well as New Mexico's lone facility in Portales). The figure also shows the relative size of ethanol production from the Midwest that is consumed in Texas.

Because there are very few ethanol production facilities in Texas, the research team was able to find data for each one. At first data from the Nebraska Department of Agriculture was used, but in the end, additional information was needed about the feedstock, so there's actually a different source for each plant company (California Air Resources Board 2011) (Air Improvement Resource, Inc. 2011) (Renewable Fuels Association 2016).

From the USDA agriculture census, the research team also found the amount of cultivated land in counties near the ethanol production facilities. That data was enough to inform an OD Matrix for truck trips to the ethanol facilities from the nearby sorghum farms.

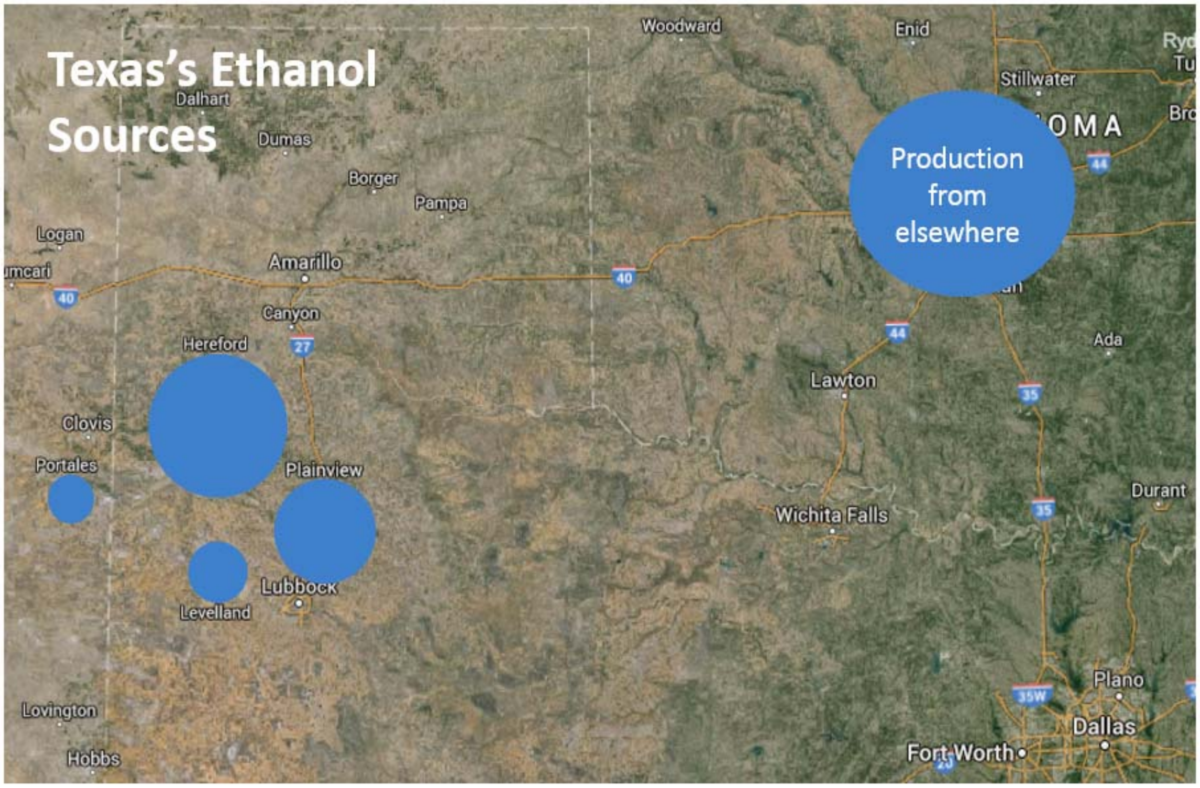


Figure 5.97: Relative Amounts of Ethanol Production by Facility

5.6.4 Commodity Flow Estimation

A standard gravity model with impedances based on the straight-line distances between zip codes converted the productions and attractions to origins and destinations. For this analysis, zip codes refer to the Zip Code Tabulation Areas (ZCTA) used by the Census Bureau. These typically coincide with postal zip codes, but are not identical (US Census Bureau, 2015).

The research team developed Python codes to convert the Economic Census data to attractions and IRS data to productions. The code used county population estimates from 2007 and 2014 to recalibrate the gas station revenue of each zip code to 2014, the most recent year for which Texas's state gasoline consumption was available (US Census Bureau, 2015). Population estimates were only available at the county level, so all ZCTAs within a county were assumed to have the same population change.

The research team at one point considered going to the individual fuel terminal companies for information about the terminals, but inspection of the IRS dataset revealed that 60 separate companies are involved in Texas fuel terminals.

A cursory inspection of fuel terminal images shows that they vary greatly in capacities; however, there is no readily accessible information on the capacities of individual fuel terminals. The same IRS dataset that lists 116 terminals spread across Texas identifies 60 separate companies that manage the terminals. This fragmentation makes it impractical to ascertain individual terminal capacities, resulting in the assumption of uniformity. The section on potential paid data sources has information on a source that might have the information needed to generate more accurate productions. Another issue with the fuel terminal data is that some fuel terminals are used to ship gasoline that does not go onto the road network, such as fuels for direct use or transport by airplanes at airports, trains at rail facilities, or ships at ports.

For attractions, the Economic Census's revenue data include receipts from non-gasoline sales at gasoline stations, such as convenience store or automotive repair operations. Using the Economic Census's revenue data to generate gasoline attractions implicitly assumes that all gasoline stations have equivalent ratios of fuel revenue to other sources of revenue. The actual ratios likely vary with population density and other explanatory variables that can improve the attraction generation.

Finally, the impedances used in the gravity model are based on Euclidean distances. Basing the impedances on network travel routes should improve the model's realism. This was considered in later sections.

The USDA has data on sorghum crop yields (US Department of Agriculture, 2015). Across three regions—the Prairie Gateway, Fruitful Rim, and Northern Great Plains—and in two separate years, the productivity of grain sorghum varied from 36.2 to 71.4 bushels per acre (Figure 5.98). This is nearly a factor of two. All of Texas's ethanol production facilities, as well as the nearby facility in New Mexico, lie within the Prairie Gateway, which had productivity from 36.2 to 47.3 bushels per acre—the least productive of the regions reported.

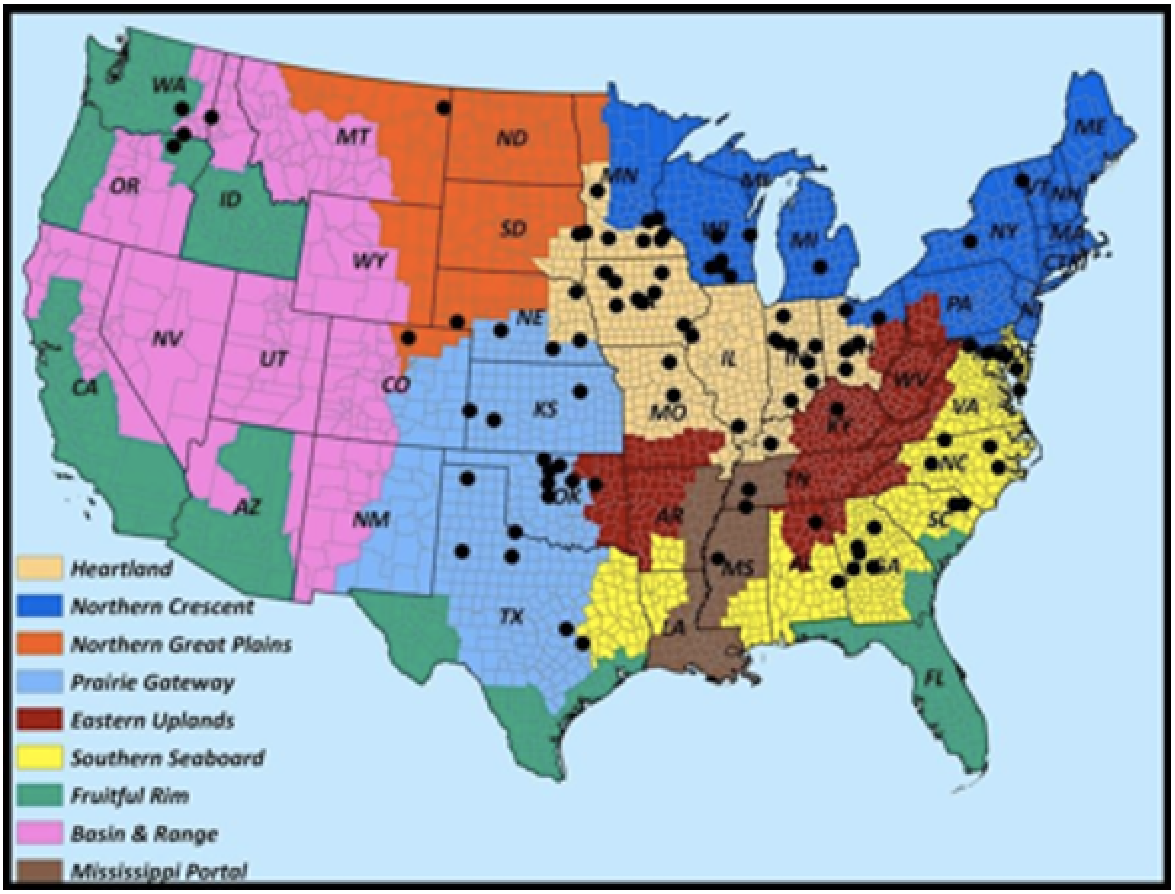


Figure 5.98: US Agronomic Regions

From an analysis of Texas's ethanol industry (Trostle, 2012):

> The total Texas High Plains annual ethanol production capacity if operating at capacity would require about 125 million bushels of grain annually. As a rule of thumb, for each one million gallon unit capacity of annual ethanol production, about 1000 bushels of grain is required per day for one year. One bushel of corn or grain sorghum—there is no major advantage to either—produces about 2.9–3.0 gallons of ethanol per bushel (56 lbs.) at current conversion technology.

Three of the four ethanol production facilities in Texas primarily use Midwestern corn as a feedstock. Those three also use small percentages of locally grown grain sorghum ranging from 2.4% to 16% of the total feedstock (California Air Resources Board, 2011) (Air Improvement Resource, Inc, 2011) (Renewable Fuels Association, 2016). The Levelland Hockley County Plant, by far the smallest in capacity, aims to use a 100% sorghum feedstock, meaning that it causes more impact on the Texas roadway network than the larger facilities (Guerrero, Amosson, Johnson, Golden, & Almas, 2010). The Abengoa Plant in nearby Portales, New Mexico also uses primarily sorghum, and is close enough to Texas that some truck shipments will cross the border (Albengoa Energy, 2011). Based on the capacities of the ethanol production facilities, their relative feedstock, and the quoted conversion between grain sorghum and ethanol, the research team estimated that at most 34 million bushels of sorghum in Texas and eastern New Mexico are moved via truck for the purpose of ethanol production. The USDA figures imply that between 2900 and 3800 square kilometers (720 to 940 thousand acres) of sorghum would need to be under cultivation.

5.6.5 Transportation

Truck Type

Gasoline and fuel ethanol are combined proportionally with certain additives at tank terminals and then loaded onto tanker trucks for transportation to gasoline stations. The most typical type of tanker truck is the combination tractor-trailer (Figure 5.99) with a typical capacity of 9,000 gallons (Hazmat 101). This type of truck includes several different compartments inside, allowing the truck to carry multiple grades of gasoline while decreasing the risk of rolling due to the limited movement of gasoline within the tanker (SpecialtyTransportation.net, 2012). Smaller single-unit tanker trucks (Figure 5.100) may also be used for transporting gasoline on shorter, mostly urban trips. The single-unit truck seen in Figure 5.100 has four axles (including one liftable axle) and a capacity of around 4,500 gallons. Three-axle tanker trucks, with a capacity of 3,000 gallons, are also used on these shorter urban trips.

Figure 5.99: 9,000-gallon Tractor-trailer Tanker Truck

Figure 5.100: 4,500-gallon Single-unit Tanker Truck

Truck Capacity

The combination tractor-trailer tanker truck in Figure 5.99 has a capacity of 9,000 gallons. Within the tanker are several compartments that allow for transporting several grades of fuel in the same truck trip. Additionally, these compartments allow the tanker truck to deposit fuel at several different gasoline stations. It should be noted that the capacity of these tanker trucks is limited by the weight of the gasoline; 9,000 gallons of gasoline weighs approximately 56,700 pounds, so the trucks are limited by 80,000-pound weight limit. Smaller single-unit trucks used for shorter, mostly urban truck trips, have a smaller capacity of 3,000 to 4,500 gallons.

Converting Volume to Equivalent Trucks

The smaller single-unit trucks are most often used for shorter trips, within the same urban area as the tank terminal where they acquire gasoline, so the impact on the Texas primary and secondary freight network will be minimal. Furthermore, the amount of single-unit tanker trucks surveyed has been minimal, indicating that relatively few trips are taken using these tanker trucks. Therefore, it has been estimated that the typical tanker truck trip will leave a tank terminal with 9,000 gallons of fuel. This volume has been used to estimate total tanker truck trips.

If an increase in single-unit tanker trucks is noted, the currently estimated truck trips can easily be converted to single-unit trips since the single-unit trucks carry a fraction (one-half or one-third) of the fuel carried by the larger combination tanker trucks.

A number of tanker truck trips may stop at multiple gasoline stations to deposit fuel. The compartmentalized tanker permits these multiple fuel-drop stops. It is anticipated that these additional fuel stops will not require a truck to leave a zip code or will not require a truck to travel a significant distance on a part of the Texas primary or secondary freight network. Therefore, these additional touring trips have not been included in this matrix.

There are several additional truck trips required to and from the tank terminals. Any additives used in the gasoline must be trucked to the tank terminals. Additionally, since the gasoline is sent to the tank terminals by pipeline in decreasing octane order, there is often some mixing between different octane fuels. This gasoline mixture, called *transmix*, must be added to lower grade gasoline or trucked back to the refinery for reprocessing since the pipeline only operates in one direction. The additives used and the transmix produced by the tank terminals generate a small amount of truck trips. These trips have not been included in this matrix.

Estimating Empty Trucks

The tanker trucks will pick up gasoline and fuel ethanol at the tank terminals, deposit the fuel at one or more gasoline stations and then return to the same or another tank terminal to pick up more fuel and repeat the process. These tankers do not pick up fuel at the gasoline stations (deposit only), so the trucks will return to the tank terminals empty.

The zip code-to-zip code matrix of number of trucks used to transport gasoline and fuel ethanol was estimated and the results are included in the appendix of this report.

5.6.6 Network Analysis

Because there are not significant truck movements of gasoline across state borders, the research team was able to directly use the OD matrix produced in the previous sections. Based on an average truckload of 9,000 gallons, the research team calculated the average value of each truck trip based on the US EIA's records for average retail gasoline costs in 2014—the year for which assignment information was available. This value was $3.225 per gallon (US Energy Information Administration, 2016). With capacities of 9,000 gallons, as established in the previous section, the value of each truck trip is approximately $29,000.

The pattern of truck trips is dictated by the distribution of tank terminals across the state. Figure 5.101 and Figure 5.102 illustrates the truck trips and value of gasoline, respectively. There are large numbers of trips coming from the population centers, where there are more tank terminals, to rural gasoline stations. Ports such as Brownsville and Corpus Christi also have significant numbers of tank terminals and relatively high truck trip densities. IH 45 north of Houston has the most traffic, which corresponds to the large number of tank terminals in Houston. There is also significant traffic on IH 35 between San Antonio and Austin. Austin has relatively few terminals, so the model indicates that trucks must make the longer journey from San Antonio to supply Austin gas stations.

The original allocation of production was based on the relative capacities of the tank terminals across the state. This assumes that tank terminals operate at similar utilization rates. It could be the case that terminals in higher demand areas use different practices from those in relatively low demand areas. Additionally, the shipment of additives to the terminals was not captured in this analysis. Those movements are much fewer, but the additives are more valuable on a per-volume basis than the final gasoline, and they generally take longer trips.

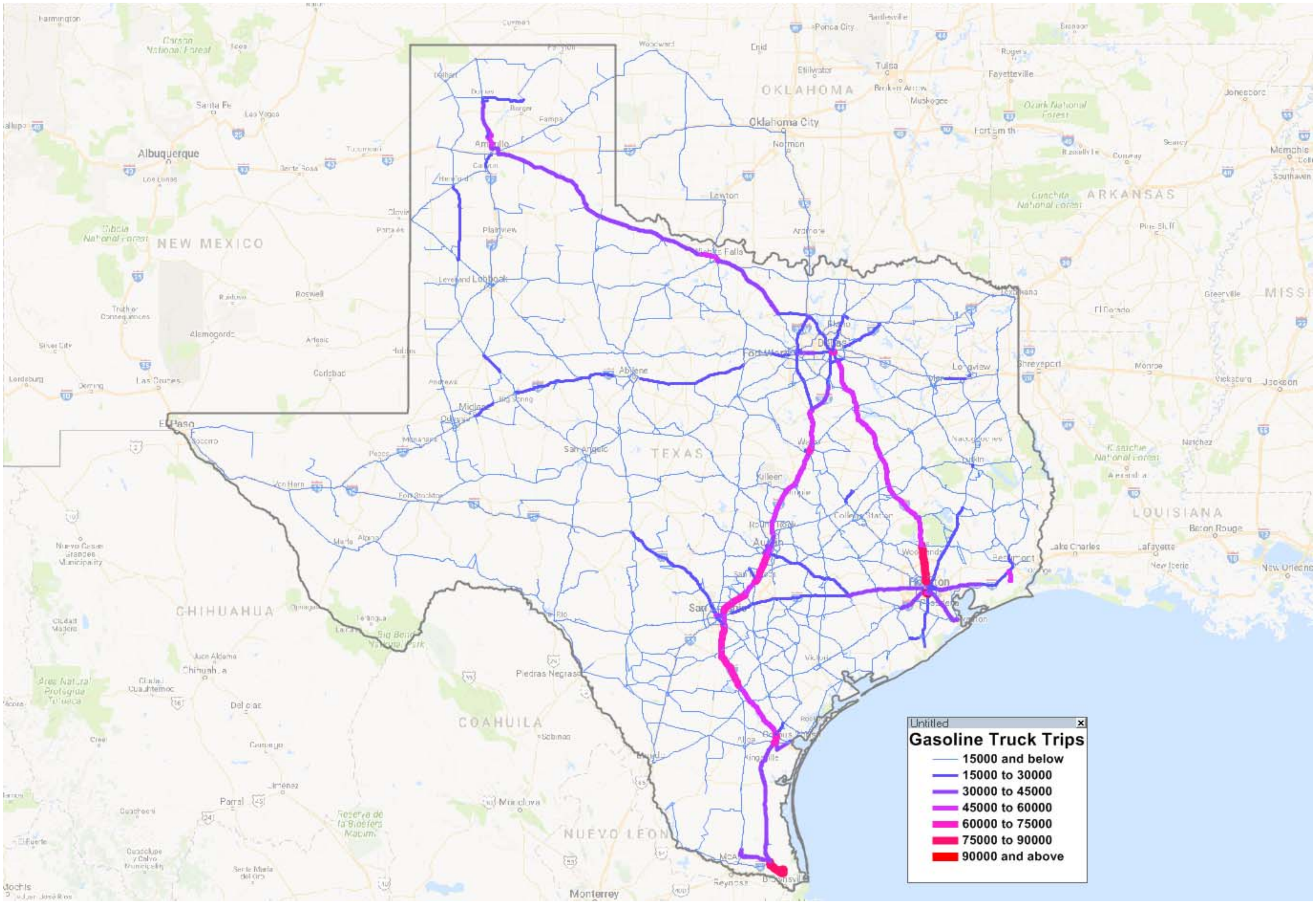


Figure 5.101: Gasoline Truck Trips

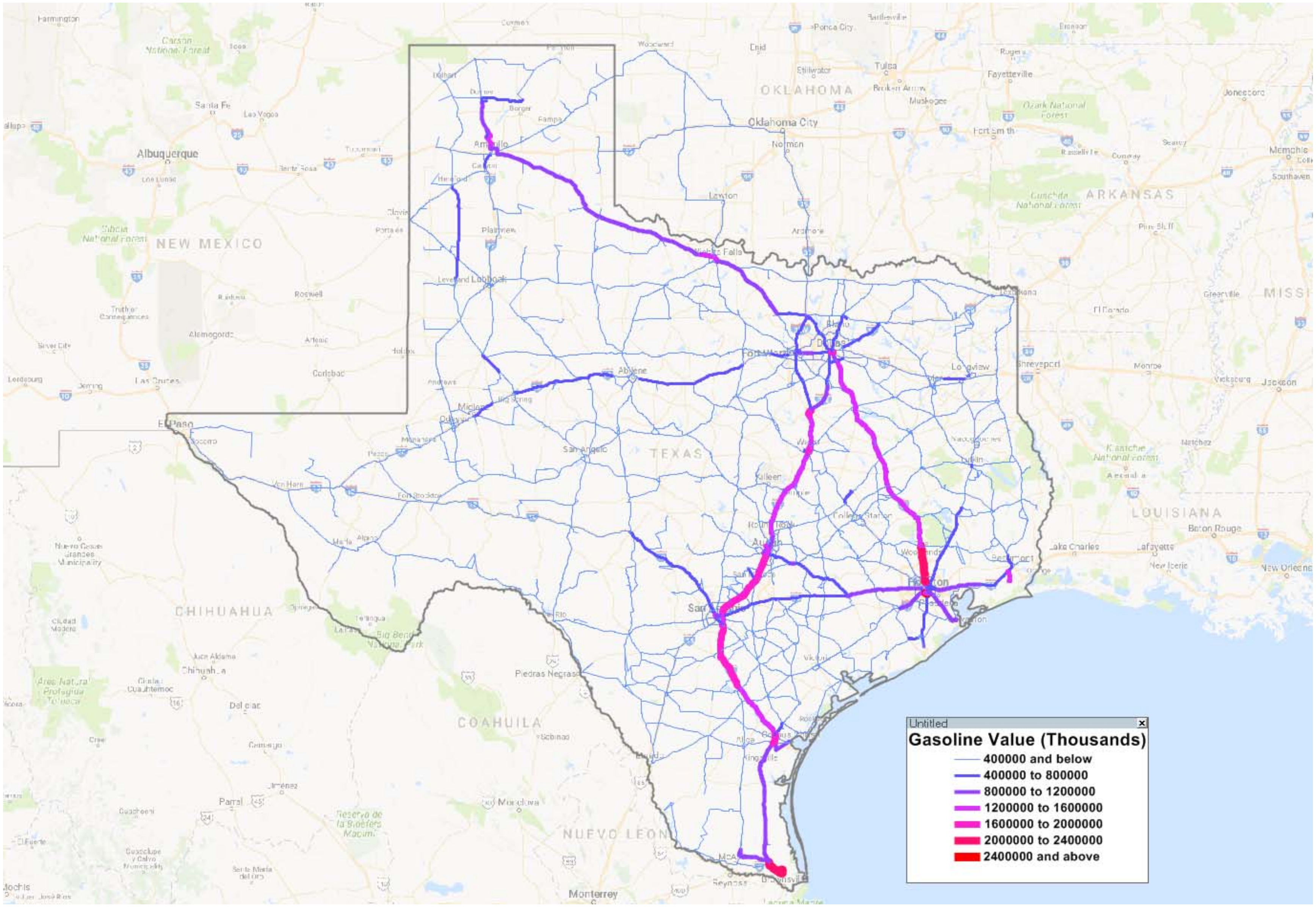


Figure 5.102: Value of Gasoline Flows

5.6.7 Compare with Transearch Data

As shown in Table 4.1, the closest commodity category to gasoline in the Transearch database is petroleum refining products (STCC 29 11). The research team processed the petroleum refining products data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.103.

The STCC category 29 11 includes all products of petroleum refining, which is why there are such high flows in Houston. This project only modelled gasoline flows, so it is difficult to draw a direct comparison on different scales. Disregarding the large flows along the Gulf Coast where most of the non-gasoline petroleum products move, there appears to be a large amount of agreement between the Transearch data and estimates developed in this project (see Figure 5.101).

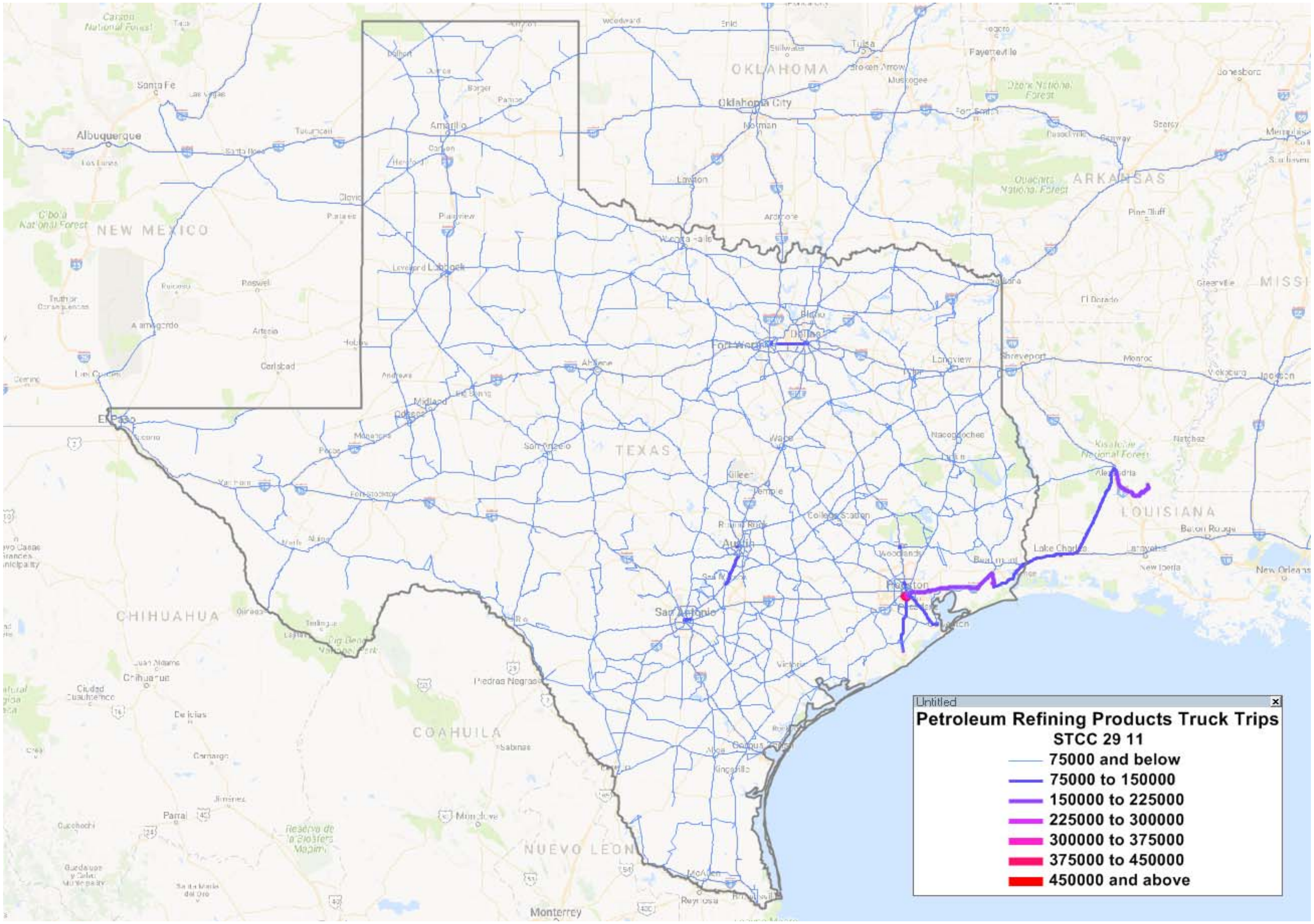


Figure 5.103: Transearch Petroleum Refining Products Truck Trips

5.6.8 Seasonal Variation

The transportation of gasoline mainly has two major components: transport from petroleum refineries and plants to gasoline terminal or consumers, and the distribution of produced gasoline to gas stations. The upstream gasoline supply chain includes three sources: petroleum refineries, ethanol plants, and fuel additives. In the U.S., petroleum refineries make up a huge proportion of gasoline production. According to EIA's recent statistic about the petroleum production, Texas accounted for about 30 percent of total U.S. refined oil capacity. Therefore, it is safe to assume that the seasonal variation of production of finished gasoline in Texas have similar trends as the entire U.S. when Texas specific data are not available.

From Petroleum Refineries to Gasoline Terminal or Consumers

Most finished oil will be transported from refineries via pipeline. However, when petroleum refineries want to send finished gasoline directly to consumers, trucks will be used (EPA, 2008). Texas inland and Gulf Coast refinery net production of crude oil and petroleum products from 2015 to the beginning of 2017 (EIA, 2017) are shown in Figure 5.104. It can be observed that gasoline production only slightly fluctuates over time. It is relatively high in the summer time, especially in July, and it is relatively low during the winter period. There is an evident decline in February, which could be caused by fewer days in that month.

The estimation chi-square value for combination of inland and Gulf Coast production is $X^2 = 12.357$, which is slightly larger than the critical value ($X^2 = 12.357 > X_t^2 = 5.58$). Based on the graph and statistic result, the gasoline flow between petroleum refineries and gasoline terminal in Texas can be concluded has minor seasonal variations.

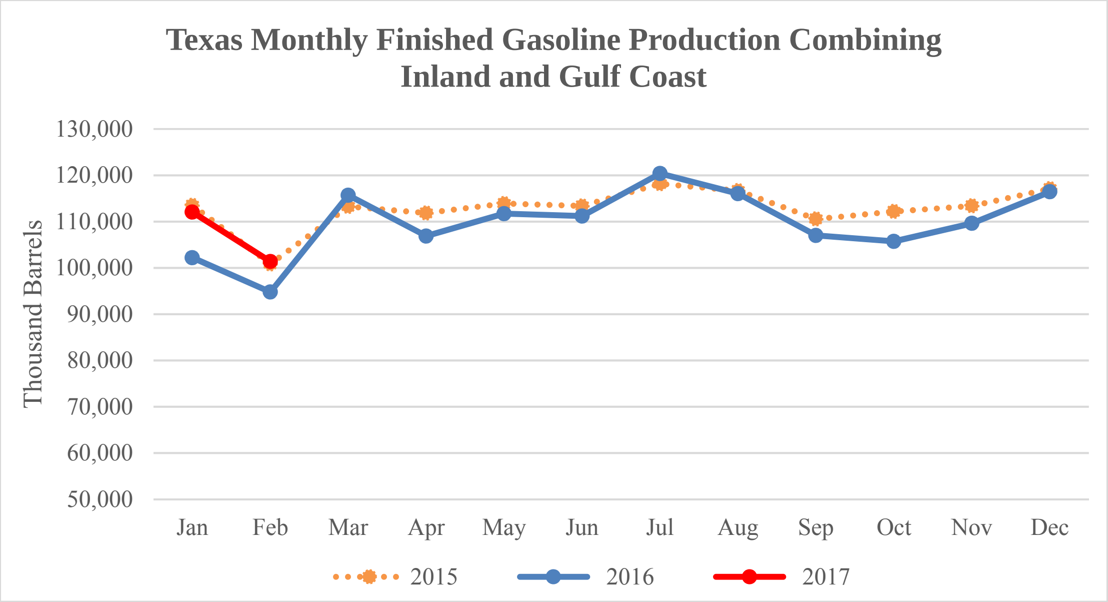


Figure 5.104: Finished Gasoline Production of Inland and Gulf Coast Refineries in Texas by Month

From Gasoline Terminal to Gasoline Stations

Since the truck flow for transporting gasoline from terminals to stations is correlated to demand for vehicle fuel, the research team examined the monthly consumption of vehicle fuel in the U.S. The EIA maintains a database of monthly U.S. domestic gasoline supply for motor vehicles. The supply from January 2014 to the middle of 2017 is shown in Figure 5.105. From 2014 to 2016, the supple was increasing at the beginning of the year (January–March) and levelled-off at a higher value for the summer months before showing a slight decline after September. The peak in summer maybe caused by higher fuel consumption from AC usage. September of 2014 and October of 2016 showed larger declines that were completely absent in 2015, and may be outliers.

The average domestic gasoline supply for motor vehicles in 2015 was used for the chi-squared test, where the chi-square value was calculated as $X^2 = 9.740$, which is slightly larger than the critical value ($X^2 = 9.740 \ > X_t^2 = 5.58$). Based on the graph and statistic result, minor but not significant seasonal variation was assumed for the transportation of gasoline from terminals to gas stations.

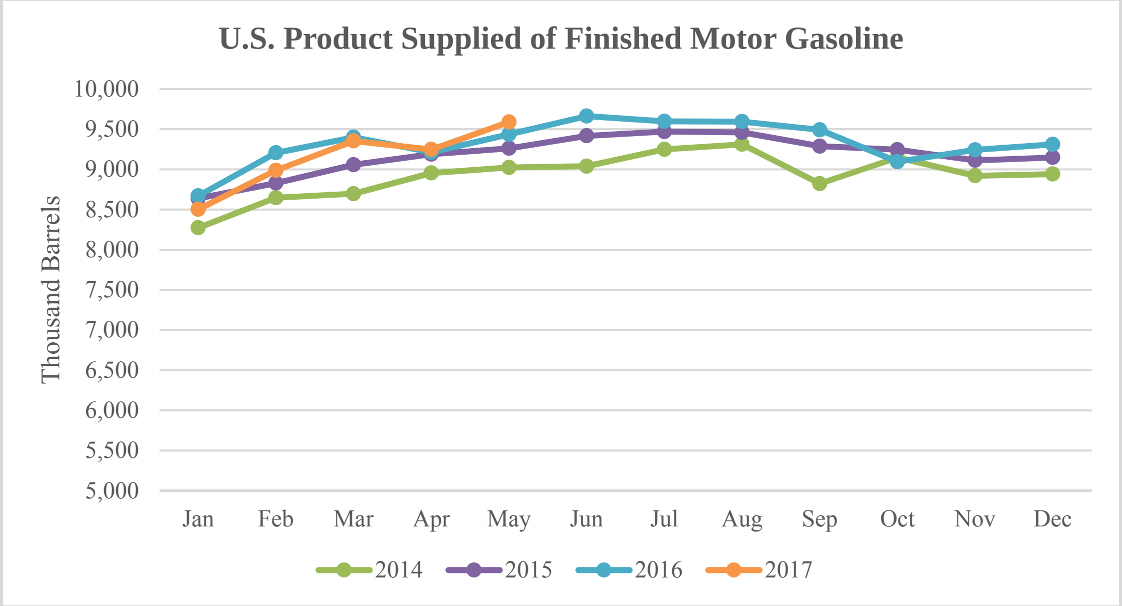


Figure 5.105: Monthly Vehicle Fuel Consumption in Texas

5.6.9 Daily Truck Trip Assignment

In the previous section, June is estimated as the month with highest number of gasoline trucks moving between gasoline terminals and gasoline stations. The daily gasoline truck trips in June is calculated using the method described in Section 4.5.3 and the results are as follows:

- Annual truck trips: 145,304
- Peak month: June
- Peak month percentage: 8.6%
- Peak month daily truck trips: 568

Figure 5.106 shows the distribution of those trucks on the network. The flow pattern is quite different from what was estimated without considering the impact of congestion (see Figure 5.101). Previously, the gasoline truck flows were mainly concentrated on the interstate highways connecting the Texas Triangle, IH 37 and US 77 connecting San Antonio and Brownsville, and US 287 connecting Dallas-Fort Worth with the Panhandle area. Even after considering the impact of congestion, IH 45 between Dallas-Fort Worth and Houston and IH 10 between San Antonio and Houston are still carrying a high number of gasoline trucks. In contrast, IH 35 between San Antonio and Dallas-Fort Worth, IH 37 and US 77 connecting San Antonio and Brownsville, and US 287 west of Dallas-Fort Worth are no longer seeing high volumes of gasoline trucks. This finding could reflect the impact of congestion on gasoline truck trip distribution and route choices. Due to congestion on those major freight corridors, gasoline coming out from gasoline terminals is more likely shipped to nearby gas stations; these trucks are more likely to choose non-congested secondary freight corridors to avoid the delays on the major freight corridors.

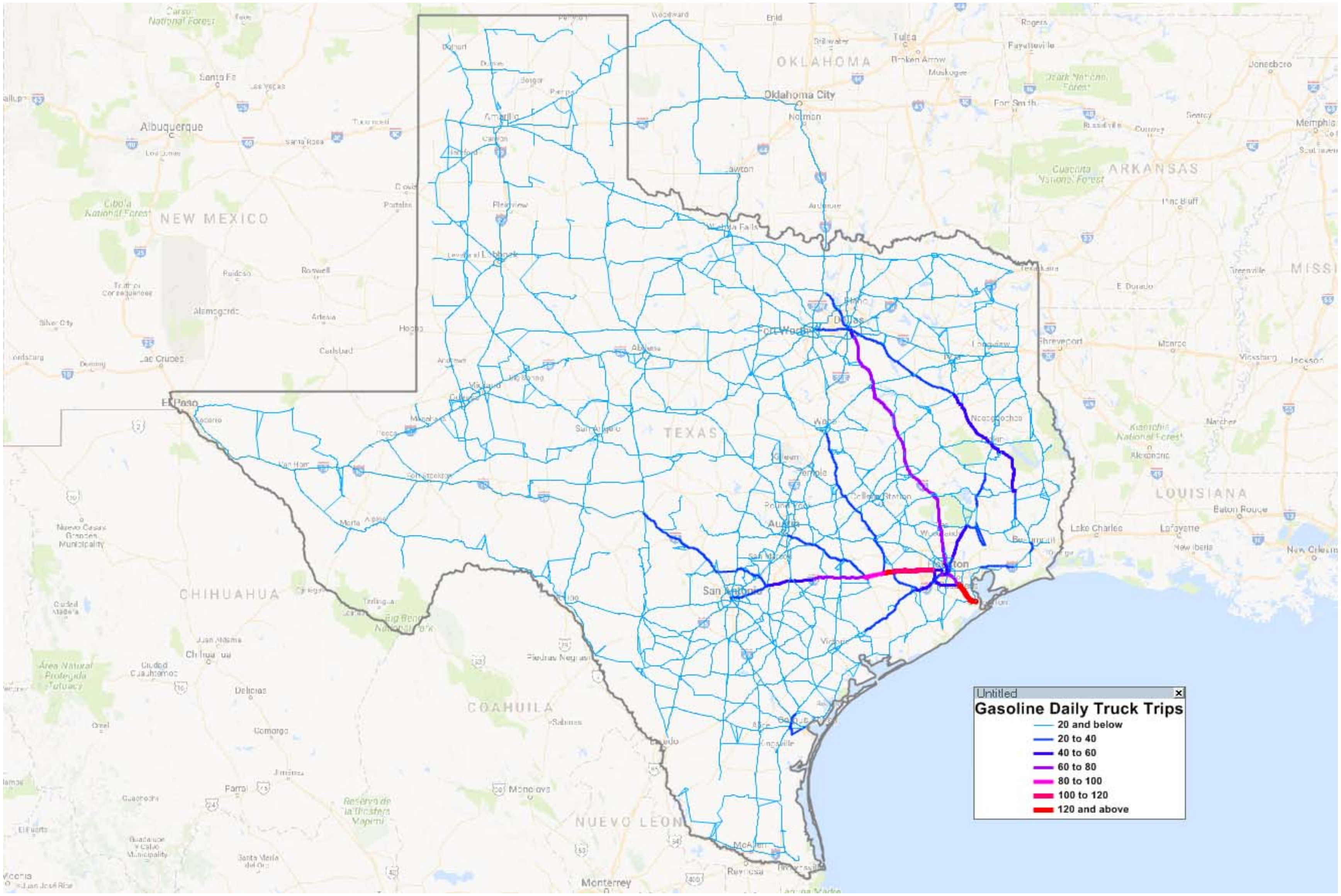


Figure 5.106: Gasoline Daily Truck Trips

5.6.10 Summary

Gasoline shipments are vital for Texas's economy, and they depend on the highway network to reach gas stations. Most of the upstream processes are handled by pipeline or rail, but fuel additives are also shipped by trucks, possibly over long distances. Even if gasoline consumption declines in the coming decades, substitutes such as ethanol depend on the same trucking infrastructure (ethanol, with its lower energy content, would actually require more trucking).

Ethanol production and consumption has grown precipitously in the past decade, as Figure 5.90 shows. While there are currently only four production facilities in Texas, this growth could make ethanol more important in the future. Each production facility will require a significant number of truck trips along rural roads to bring in grains for processing and ship out distillers grains for use as livestock feed. Each ton of grains brought to the facility results in over 400 L of ethanol and 300 kg of livestock feed that will need to be shipped out. Much of the supply chain going into and out of the facility is by rail, but a significant portion (depending on the grains used) uses trucks that will travel TxDOT highways.

This study focused on the movement of gasoline trucks between gasoline terminals and gasoline stations. The network analysis (without considering the impact of congestion) shows that large numbers of trips are coming from the population centers, where there are more tank terminals. IH 45 north of Houston has the most traffic, which corresponds to the large number of tank terminals in Houston. Ports such as Brownsville and Corpus Christi also have significant numbers of tank terminals and relatively high truck trip densities. Given that congestion could have significant impact on gasoline trucks' destination and route choices, shippers may choose closer destinations (gas stations) and non-congested lower level roadways to avoid the congestion on major highways.

A minor but not very significant seasonal variation was observed associated with the consumption of gasoline fuel and therefore the transportation of gasoline from terminals to gas stations. Summer is shown to be the season with higher demand for gasoline. Several highways from/to Houston carry more than 120 gasoline trucks each day in June, for example.

5.7 Motor Vehicle

5.7.1 Background

The motorized vehicle industry continues to grow, especially in Texas. There has been continual growth in Texas vehicle registrations over the past few years. Additionally, there is a constant flow of parts and vehicles along an axis from Ontario/Michigan to northern Mexico. The Texas-Mexico Automobile Supercluster, a term coined by the Bexar County Office of Economic Development, is located along this axis and includes a large collection of both automobile supply and assembly plants in Texas and northern Mexico. Toyota opened a new truck assembly plant in San Antonio in 2006, a time when many assembly plants were on the brink of closure nationwide. GM also maintains an assembly plant in Arlington, producing midsize to large SUVs.

5.7.2 Supply Chain

The modeling focus will be the flow of new passenger vehicles from the automotive assembly plants to new car dealerships (Figure 5.107). Due to the huge number of vehicle parts producers across a wide geographical area and the varying transportation methods used to transport parts to assembly plants, the modeling focus is limited to the final product in the supply chain, the newly assembled passenger vehicles.

Additionally, the used car market has been omitted. Used cars can be sold through new or used car dealerships or through personal transactions and are most often transported themselves, minimizing the impact to TxDOT-maintained roads.

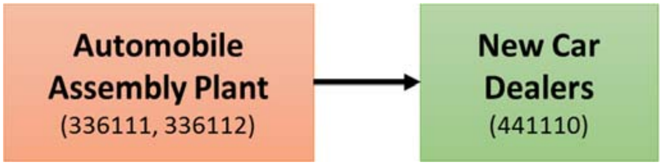


Figure 5.107: Motor Vehicles Supply Chain

5.7.3 Datasets

The following free public data sources and non-public data sources were considered for use in this modeling effort:

Public Data Sources:

- Texas Department of Motor Vehicles (TxDMV):
    - Number of vehicles registered – not included in this modeling effort since we cannot determine whether registrations are for new or used vehicles.
    - Dealer locations – included in this modeling effort. The list of dealerships could be downloaded from the TxDMV website. The list includes all new and used car dealers and trailer dealers and reports the municipality and county of each dealer (Texas Department of Motor Vehicles (TxDMV), 2016).
- US Census Resident Population Data – included in this modeling effort. The total number of new vehicles sold in the United States in available from the WardsAuto data set (see below), so the total number of new vehicles sold in Texas is estimated using state population data from 2010 (United States Census Bureau, n.d.).
- TWC Data – new car dealerships, sorted by NAICS code, were included in this modeling effort.

Non-Public Data Sources:

- 2010 Surface Transportation Board (STB) Waybill Sample – included in this modeling effort. The data includes a sample of waybills in Texas from a stratum population (RAILINC, 2012).
- WardsAuto – national automotive sales data is included in this modeling effort. Since it was determined that a majority of the intrastate shipments of new vehicles are via rail, plant production and inventory data was not used and is not available due to cost (WardsAuto, 2016).

- National Automobile Dealers Association – not included in this modeling effort since a list of new car dealerships in Texas was not available, only a total number of dealerships (National Automobile Dealers Association (NADA), 2016).
- Elm Analytics – automobile supplier data was not included in this modeling effort since the shipments of parts to assembly plants were not modeled. Additionally, the data was not comprehensive across the state of Texas. Several regions were included but it appears that most other regions had not yet been studied (Elm Analytics, 2016).

Table 5.21 includes the NAICS codes of assembly plants, motor vehicles, and dealerships. Additionally, the STCC codes for assembled motor passenger cars and motor trucks, encountered in the STB Waybill Sample, are included as a crosswalk.

Table 5.21: Crosswalk NAICS and STCC code for motor vehicles

2007 NAICS Code	Category	STCC Code	Category
336111	Automobile and Light Duty Motor Vehicle Manufacturing	371110	Motor Passenger or Air Cars, Assembled
336112	Light Truck and Utility Vehicle Manufacturing	371120	Motor Trucks or Truck Tractors, Assembled
441110	New Car Dealers	N/A	

After new vehicles are produced at an automobile assembly plant, most are loaded onto train automobile transport cars. Both the General Motors assembly plant in Arlington and the Toyota truck assembly plant in San Antonio have railroad automotive ramps at or just adjacent to their assembly plants. Aerial images of Union Pacific Arlington automotive ramp are shown in Figure 5.108 (Google, 2016).

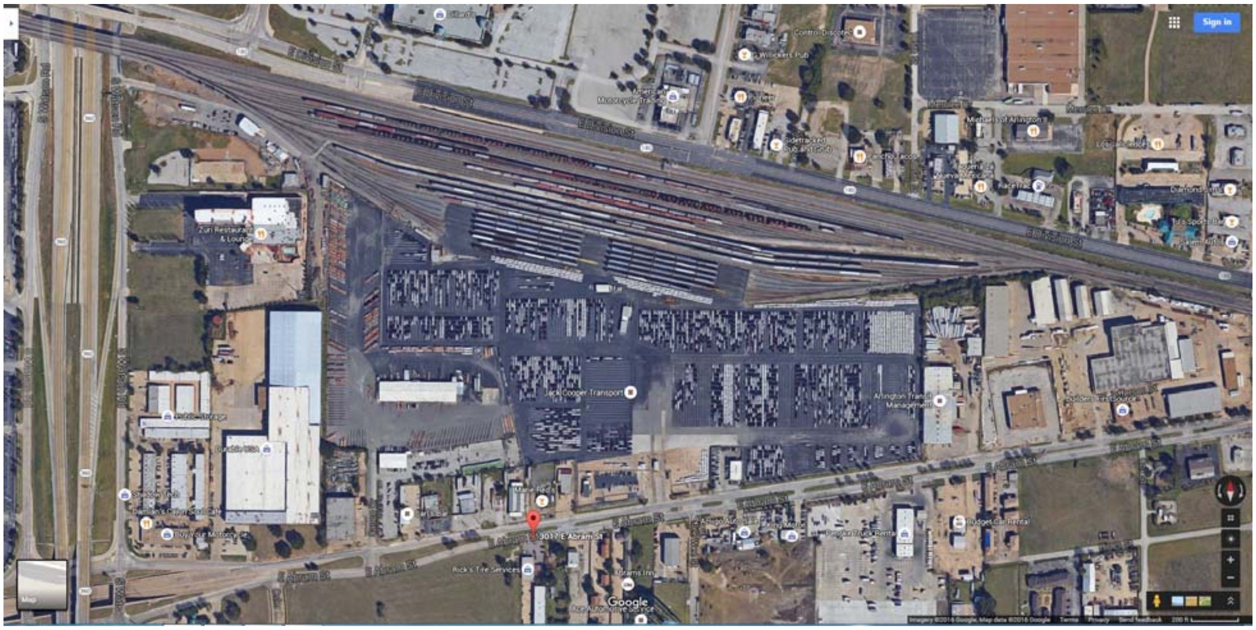
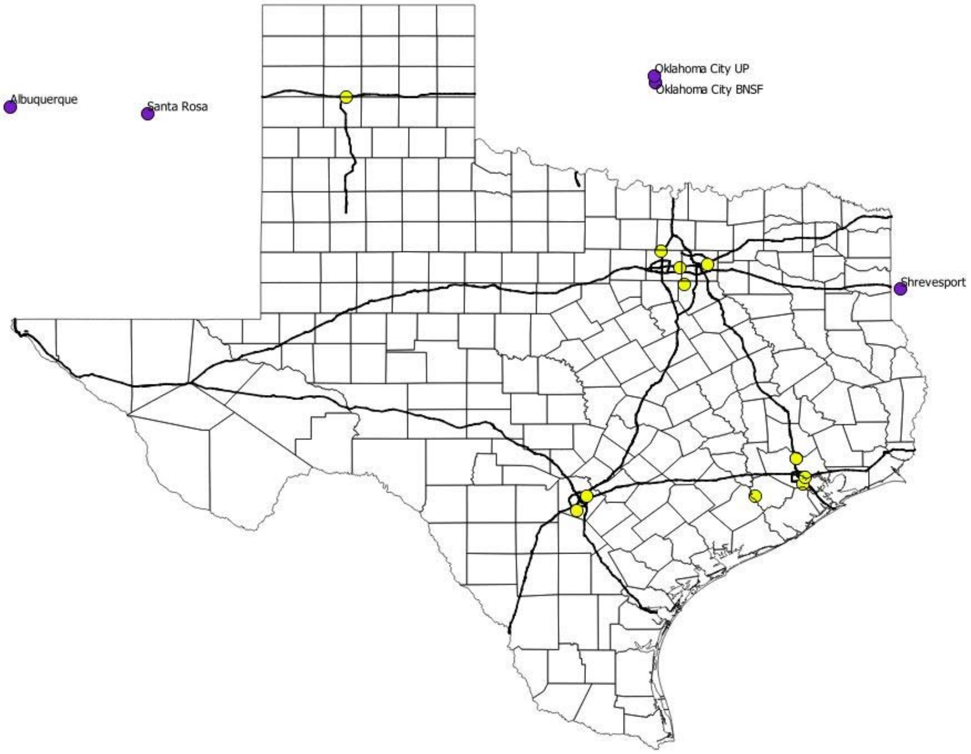


Figure 5.108: Union Pacific Arlington Automotive Ramp

In addition to the two automobile loading ramps, there are ten automobile unloading ramps in Texas (including the aforementioned GM ramp that serves as both a loading and unloading ramp) and several automobile ramps in surrounding states that transport motor vehicles to car dealerships (Transportation Technology Center, Inc., 2016). A map of the locations of these automobile ramps is provided in Figure 5.109. The ramps in Texas are represented by yellow circles and the ramps outside Texas used for this modeling effort are represented by purple circles.

A significant proportion of motor vehicles are transported by rail from assembly plants to these unloading ramps and then transported by truck to their final destination dealership. The motor vehicles not transported by rail are transported by truck from the assembly plants to nearby locations.

Of the five automobile ramps outside Texas, two are in New Mexico, two are in Oklahoma, and one is in Louisiana. It is anticipated that the two New Mexico ramps will transport a significant number of vehicles to El Paso and surrounding counties and that the Shreveport, Louisiana ramp will transport vehicles to counties in East Texas.



(Yellow circles = ramps in Texas; purple circles = ramps outside Texas)

Figure 5.109: Location of Automotive Ramps Offloading Vehicles to Texas Dealerships

As represented by the map above, automotive ramps are generally located near major population centers, with four ramps in the Dallas-Fort Worth area, four ramps in Houston, two in San Antonio, and one in Amarillo. There is also a wide range of sizes of these ramps. The Kansas City Southern ramp in Beasley, Fort Bend County is very small compared to the nearby Union Pacific Westfield ramp in Houston, Harris County.

5.7.4 Commodity Flow Estimation

The total productions and attractions for new motor vehicles in Texas were estimated by disaggregating the WardsAuto national sales data (11,772,526 vehicles) for the year 2010 to a statewide level using the 2010 Census population data. It was determined that the total sales in Texas were equal to 958,805 new vehicles by multiplying the WardsAuto national sales number by the proportion of the US population within Texas.

$$\begin{aligned} &\mathit{Total\ new\ vehicles\ sold\ in\ Texas} \\ &\qquad = 11{,}772{,}526\ (\mathit{national\ sales}) * \frac{25{,}145{,}561\ (\mathit{TX\ population})}{308{,}745{,}528\ (\mathit{US\ population})} \\ &\qquad = 958{,}805\ \mathit{vehicles} \end{aligned} \qquad (5.5)$$

The production of motor vehicles in Texas was assumed to take place at an assembly plant, an in-state automotive ramp, or an out-of-state automotive ramp. This assumption was made since most of the longer haul vehicle movements are by rail. Shorter haul trips from the assembly plants in Texas by truck are considered in this methodology. Any discrepancies between the amount of vehicles offloaded at in-state ramps, the vehicles trucked from in-state assembly plants, and the amount of estimated new vehicles sold in Texas (958,805) are accounted for by importing vehicles from nearby automotive ramps in other states.

The attractions of motor vehicles were determined on a county level by a combination of the amount of new car dealerships, amount of total (new and used) car dealerships, and the population in each county.

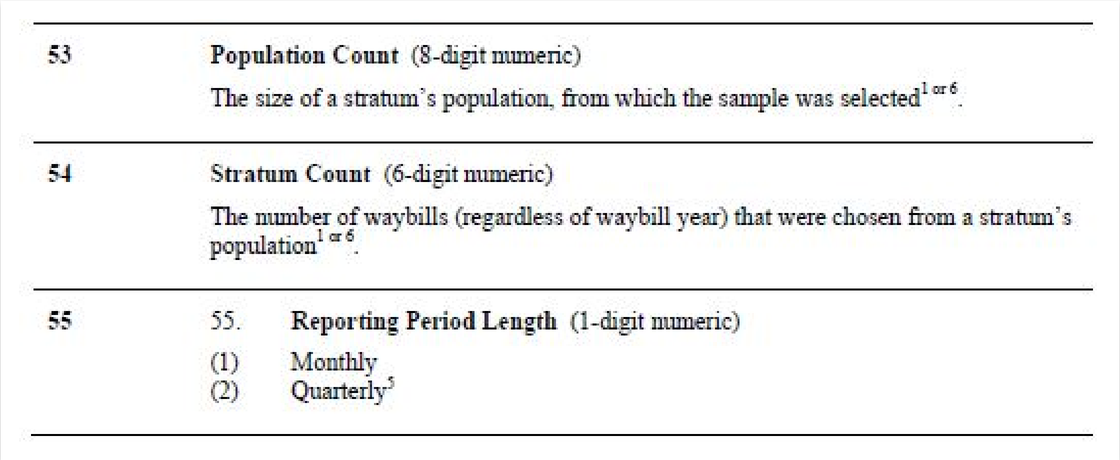
Once the production at each automotive ramp and assembly plant and the attractions for each county were determined, an algorithm was run to allocate the vehicle attractions for each county to its closest ramp. The algorithm allocated county attractions to their closest automotive ramp until that ramp reached its capacity (total vehicles offloaded in 2010). Once the capacity for a ramp was reached, the next furthest county from that ramp (that should have drawn its attractions from the ramp) would instead draw from its second closest ramp.

Five out-of-state ramps were used in this algorithm. The ramp in Shreveport, Louisiana supplied a significant number of counties in far east Texas and the two ramps in New Mexico (Albuquerque and Santa Rosa) supplied a significant number of counties in the El Paso region due to the lack of any in-state ramps nearby. The two ramps in Oklahoma City supplied a very limited number of counties near the bottom of the Texas Panhandle. Most of these allocations resulted from a county's attractions being redirected from its preferred ramp after capacity was reached.

The algorithm also allocated vehicles from Texas ramps to out-of-state destinations. Several ramps in the Dallas-Fort Worth area had additional capacity and this capacity was allocated to Oklahoma. Additionally, the Harris County ramp had excess capacity that was allocated to Louisiana.

Railroad Automotive Ramps

The number of vehicles offloaded at each automotive ramp was determined by aggregating data in the 2010 STB Waybill Sample for Texas. The data was first filtered by waybills with destinations in Texas and then by STCC Code for motor passenger or air cars, assembled (371110) and motor trucks or truck tractors, assembled (371120). From here, the data was separated out based on county FIPS (Federal Information Processing Standard) code to determine the amount of vehicles offloaded at each automotive ramp. The total number of carloads offloading vehicles in Texas could be estimated by multiplying the number of cars in each waybill sample by the population count divided by the stratum count. Figure 5.110 is an excerpt of the 2010 STB Waybill Sample legend.



53	**Population Count** (8-digit numeric) The size of a stratum's population, from which the sample was selected[1 or 6].	
54	**Stratum Count** (6-digit numeric) The number of waybills (regardless of waybill year) that were chosen from a stratum's population[1 or 6].	
55	55.	**Reporting Period Length** (1-digit numeric)
	(1)	Monthly
	(2)	Quarterly[5]

Figure 5.110: 2010 STB Waybill Sample Legend (RAILINC, 2012)

Once the total number of carloads was determined, the amount of carloads was multiplied by 10.5 for STCC Code 371110 and 8 for STCC Code 371120 to estimate the number of vehicles offloaded at each ramp. Since it is estimated that a rail vehicle carrier can transport approximately 12 passenger cars or 8 SUVs or light trucks, an average carload capacity of 10.5 was assumed for STCC Code 371110. The capacity for STCC Code 371120 was fixed at 8 because this category includes only trucks.

Table 5.22 presents the number of estimated vehicles offloaded at each ramp.

Table 5.22: Vehicles offloaded at railroad ramps

FIPS	County	Railroad	Facility	STCC 37111		STCC 37112		Total
				Carloads	Vehicles	Carloads	Vehicles	
48029	Bexar	UP	Kirby SA	9160.011	96180.1155	1639.985	13119.88	**109300.0**
48113	Dallas	UP	Mesquite	14280.03	149940.315	3720.014	29760.112	**179700.4**
48139	Ellis	BNSF/ UP	Midtex	2922.59	30687.195	2441.527	19532.216	**50219.4**
48157	Fort Bend	KCS	Beasley	879.6772	9236.6106	0	0	**9236.6**
48201	Harris	BNSF	Pearland	40.04012	420.42126	80.11019	640.88152	**1061.3**
48201	Harris	KCS	Beasley	1079.716	11337.018	0	0	**11337.0**
48201	Harris	UP	Various	24240.06	254520.63	6600.07	52800.56	**307321.2**
48375	Potter	BNSF	Amarillo	1281.541	13456.1805	560.6364	4485.0912	**17941.3**
48439	Tarrant	BNSF	Alliance	4525.403	47516.7315	1041.218	8329.744	**55846.5**
48439	Tarrant	UP	Arlington	2680.035	28140.3675	0	0	**28140.4**
			Total	**61089.1**	**641435.6**	**16083.6**	**128668.5**	**770104.1**

The above totals appear consistent with the size of each ramp, except for the BNSF Pearland ramp in Harris County. The total of 1,061 vehicles is much less than the expected vehicle movements through the facility. Historical aerials were viewed for the BNSF Pearland ramp to determine if this number of vehicle movements is correct (National Environmental Title Research, LLC, 2016).

These historical aerial images show little to no activity at this ramp. No rail carriers appear to be on site and only a handful of vehicles. The number of vehicle movements through the facility estimated by the 2010 STB Waybill Sample appears to be correct. Therefore, the modeling approach proceeded with these ramp estimates.

Automotive Assembly Plants

The number of vehicles transported by truck from the GM Arlington and Toyota San Antonio assembly plants was estimated using a method similar to the railroad automotive ramps. However, instead of filtering the 2010 STB Waybill Sample to search for waybills ending in Texas, the data was filtered to search for waybills originating in Texas. Furthermore, waybills originating in Bexar and Tarrant Counties were aggregated to provide an estimate on the vehicles shipped by rail from each assembly plant.

At the GM Arlington plant, an estimated 282,000 vehicles were produced in 2010 (Tarrant Business, 2012). The number of railroad carloads originating in Tarrant County is multiplied by 8 to estimate the number of vehicles (203,840) loaded at the Arlington automotive ramp. It is assumed that the remaining vehicles produced at the GM Arlington plant (78,160) are shipped by truck from the facility.

Similar to the methodology for the GM Arlington plant, it is estimated that 200,000 vehicles were produced in 2010 at the Toyota San Antonio assembly plant (Texas Wide Open for Business, 2014). The waybill sample estimates that 105,648 vehicles were shipped by rail from the plant, meaning that the remaining 94,352 vehicles were shipped by truck.

Dealerships

The total new vehicle attractions for each county were estimated as a function of the number of dealerships and the population within each county. A list of approximately 22,500 dealerships (both new and used) was obtained from the TxDMV and a list of over 1,400 new car dealerships was obtained from the TWC. The number of dealerships in each dataset was aggregated for each county. The total attractions for each county was determined by multiplying the total vehicles sold in Texas (958,805) by a weighted average of the proportion of TWC dealerships (50%), the proportion of TxDMV dealerships (25%), and the proportion population (25%) within each county compared to the entire state of Texas.

For any counties where the number of TWC dealerships equals zero, the total attractions within that county were set equal to zero and the attractions were redistributed throughout all other counties proportionally. It is anticipated that the TWC dealership list contains the most accurate information regarding the number of strictly new car dealerships in the state. However, the TWC data was used for other commodities and it was anticipated that several errors or omissions occurred throughout the data. Therefore, the weighted average including the TxDMV dealership list and the county populations was instituted as an attempt to counteract any errors in the data.

5.7.5 Transportation

Truck Type

Automobiles are transported from railroad automotive ramps and manufacturing plants using automobile transporter trucks. The most typical truck configuration is the stinger-steered automobile transporter like the one shown in Figure 5.111 (Oregon Department of Transportation, 2016), where a coupling device is mounted behind the rear tires on the back of the tractor. Auto transporter trailers can also be mounted via the fifth wheel coupling mechanism to a traditional truck tractor like the one shown in Figure 5.112 (Oregon Department of Transportation, 2016) for another truck combination. The stinger-steered transporters provide additional capacity, accommodating up to ten small vehicles or eight larger SUVs or pickup trucks, and allow for better maneuverability. The conventional truck tractors with auto transporter trailer have a slightly smaller capacity, traditionally limited to seven smaller vehicles and six SUVs or pickup trucks, but provide greater flexibility in using different truck tractors.

Figure 5.111: Stinger-steered Automobile Transporter Truck

Figure 5.112: Conventional Truck Tractor with Automobile Transporter Trailer

New vehicles can also be transported using pickup trucks with an attached trailer that can carry three vehicles. However, these pickup truck trailers are most often used to transport vehicles between dealerships, rather than from railroad automotive ramps to dealerships, and so are not included in this study.

Truck Capacity

The stinger-steered automobile transporter trucks can accommodate up to ten smaller vehicles or eight larger SUVs or pickup trucks. Units traditionally operate with six to ten vehicles on board. The conventional truck tractors with auto transporter trailer can accommodate up to seven smaller vehicles or six larger SUVs or pickup trucks. These combination trucks traditionally operate with six or seven vehicles.

Converting Vehicles to Equivalent Trucks

Based on visual observations, it was determined that stinger-steered automobile transporter trucks account for approximately 75% of the total new vehicle truck transport trips, with conventional tractor-trailers accounting for the remaining 25% of trips. Furthermore, it was determined that stinger-steered transporter trucks will carry 9 or 10 new sedans during a run or 6, 7, or 8 larger SUVs or pickup trucks. Conventional tractor-trailer transporters will carry seven sedans or six larger vehicles during a run.

Cars accounted for 52% of total nationwide vehicle sales in 2010, while SUVs, minivans, and pickup trucks accounted for the remaining 48% (Auto Alliance, 2016). From these figures, it can be estimated (and confirmed by visual observations) that a stinger-steered automobile transporter truck will carry 8.5 vehicles on average while a conventional tractor-trailer transporter will carry 6.5 vehicles. The total average vehicle load on a truck transporter is eight vehicles, determined using the weighted average of both types of automobile transporters.

Estimating Empty Trucks

Automobile transporters may often stop at more than one destination to drop off vehicles. However, it is anticipated that these touring trips will remain within the county. These additional trips will not impact the OD matrix due to the intra-county movements.

The transporter trucks may be used to transport used or wrecked vehicles from dealerships to other locations after dropping off their full load of new vehicles. Since the flow of used or wrecked vehicles is not estimated in this commodity model, these trips have not been included in the OD matrix. Due to the quick depreciation value of new vehicles, these additional truck trips will carry much less monetary value than a truck trip with entirely new vehicles.

The county-to-county matrix of number of trucks used to transport new motor vehicles was estimated and the results are included in Appendix 1 of this report.

5.7.6 Network Analysis

The truck trips for the transport of motor vehicles from assembly plants to new car dealers estimated in the previous section are assigned to the created freight network following the procedure described in Section 4.3. Results are represented in Figure 5.113.

Truck trips for motor vehicles are primarily concentrated along interstate highways throughout the state, as seen in Figure 5.113. Notable segments include IH 35 between San Antonio and Austin, IH 10 from Houston to the Louisiana border, and IH 35 and IH 20 in the vicinity of the Dallas-Fort Worth Metroplex. The largest concentrations of truck trips appear near railroad automotive ramps. US 84 from the New Mexico border to US 385 also has a high concentration of truck trips. Two automotive ramps in New Mexico, one at Santa Rosa and one at Albuquerque, supply many vehicles to western areas of the state.

The average new vehicle sale and lease price in the United States in 2010 (estimated year) was $26,850 (Statistica, 2016). This value was utilized to provide an estimate of the value of motor vehicles transported across the Texas primary and secondary freight network in Figure 5.114. The light blue lines represent roads that transport less than $600 million of motor vehicles per year. The thick red lines are the roads that transport more than $3.6 billion of motor vehicles per year. The highest value segments are located in urban areas, notably San Antonio and Houston.

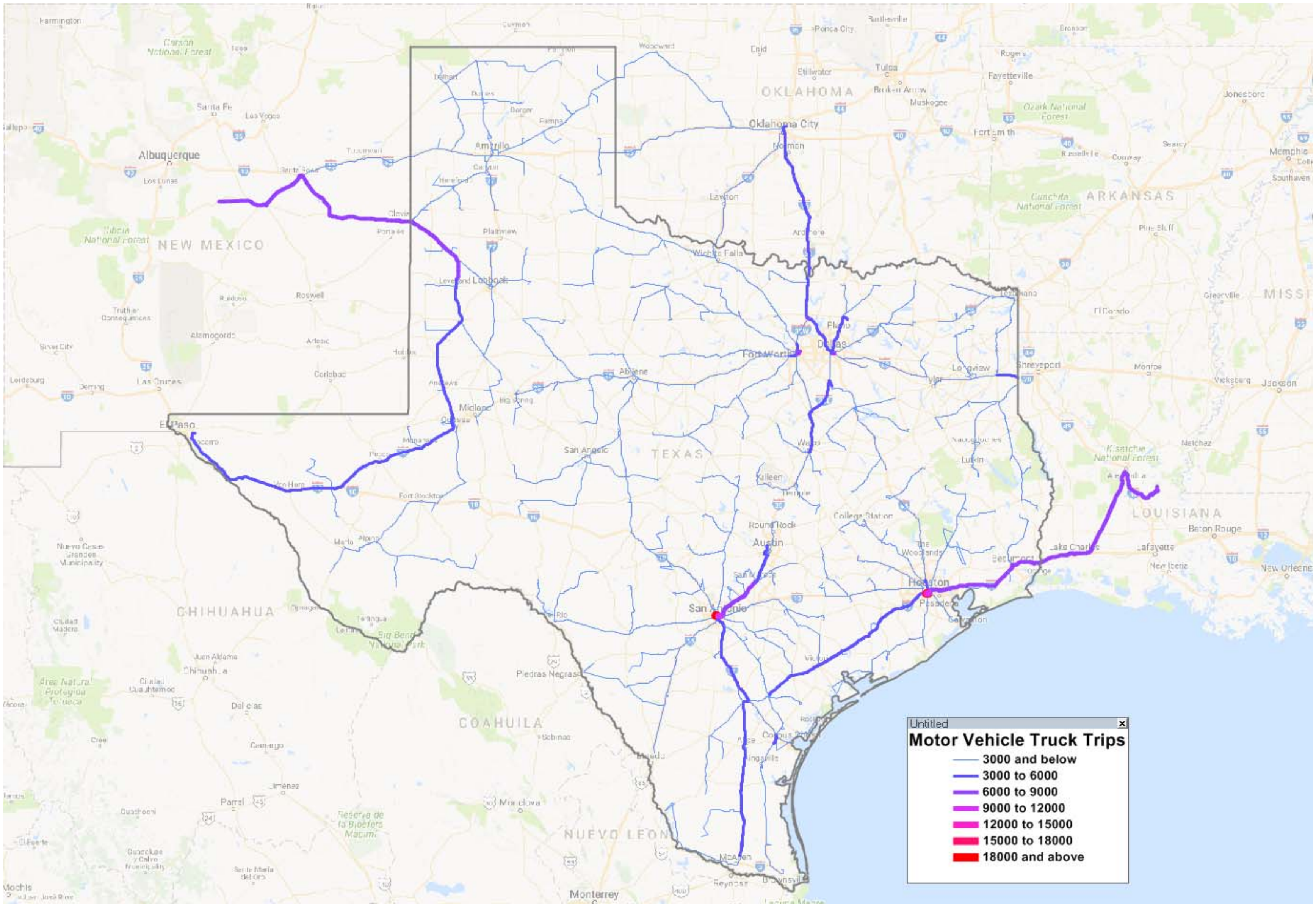


Figure 5.113: Motor Vehicle Truck Trips

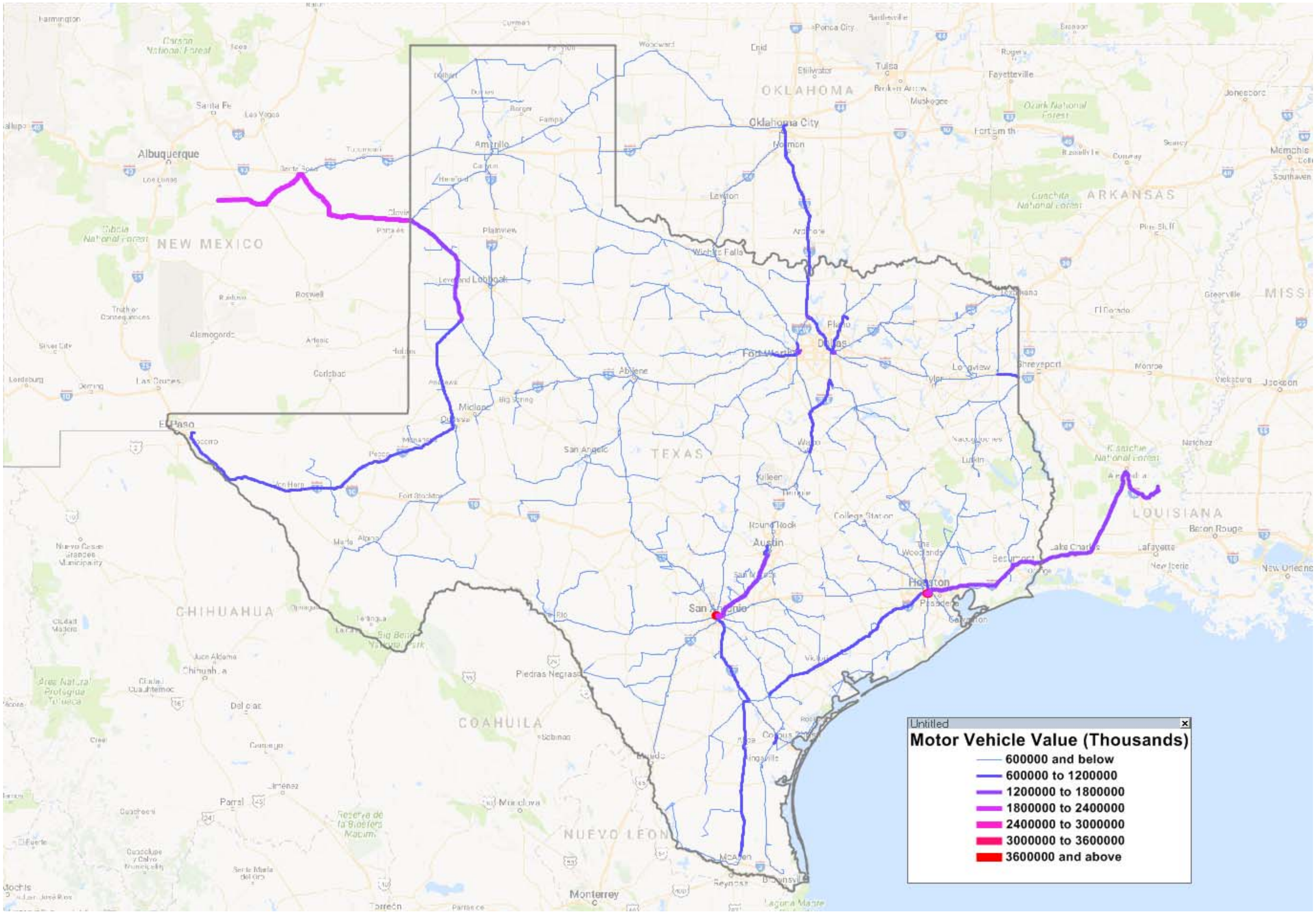


Figure 5.114: Motor Vehicle Value

5.7.7 Compare with Transearch Data

As shown in Table 4.1, Transearch database has a commodity category for motor vehicles (STCC 37 11). The research team processed the motor vehicle data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.115.

Based on Transearch data, IH 35 is the major corridor for carrying motor vehicle truck trips, especially the section from the Mexico-Texas border to San Antonio and the section between Austin and Dallas. There is a good overlap between Transearch motor vehicle truck trips (Figure 5.115) and the motor vehicle movements modelled in this project (Figure 5.113), although the Transearch data has greater flows along the IH 35 corridor. This could be because this study focused on the truck movement between assembly plants and dealerships within Texas, while Transearch data include import, export and trucks trips passing though Texas. The large amount of motor vehicle trucks on IH 35 shown in Figure 5.115 starting from Mexico-Texas border proves this.

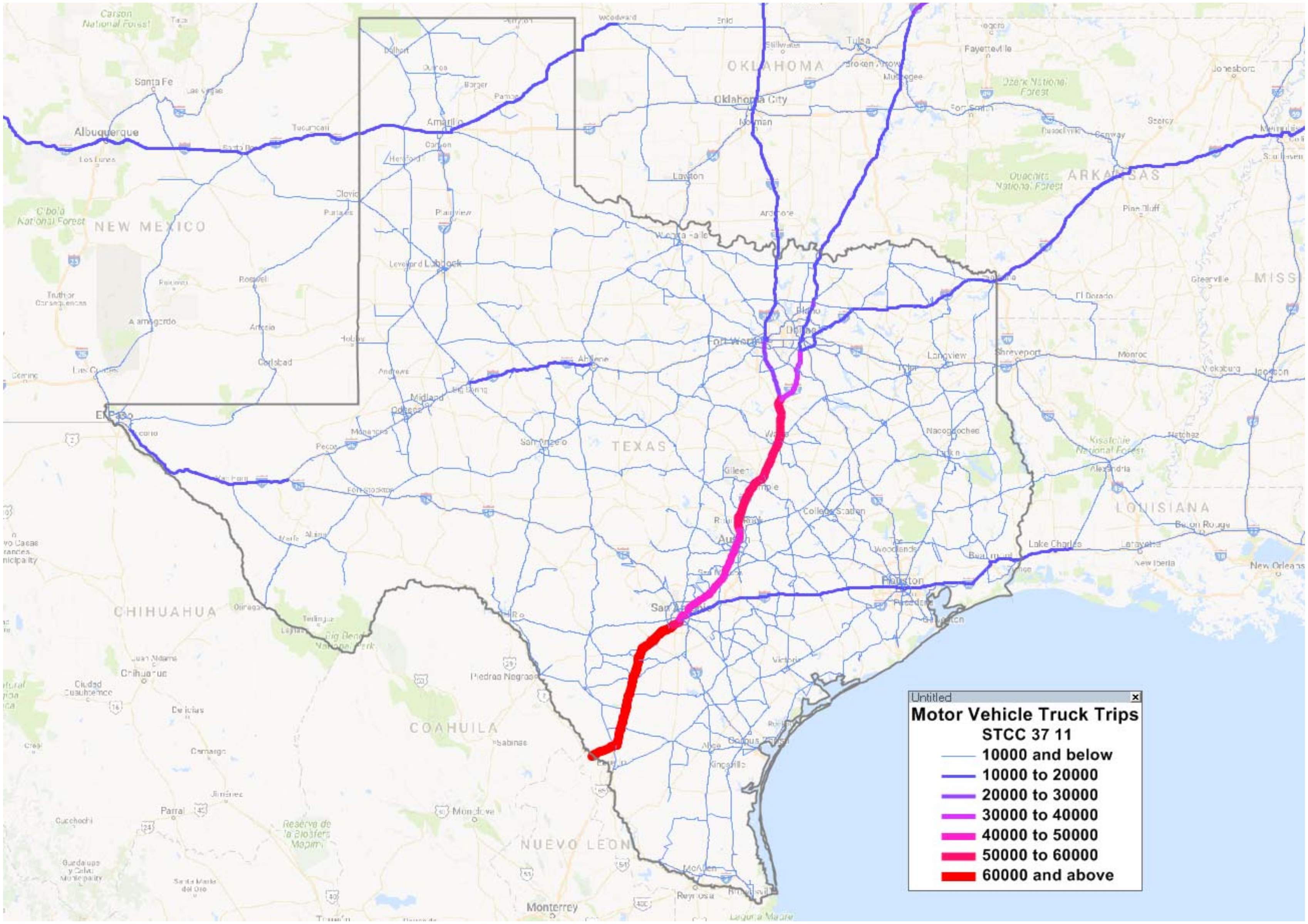


Figure 5.115: Transearch Motor Vehicle Truck Trips

5.7.8 Seasonal Variation

The transportation of motor vehicles from automotive assembly plants to new car dealerships was examined for the study of seasonal variations. Monthly vehicle sales data can be used to estimate the seasonal variation of vehicle transportation from assembly plants to dealerships. However, only national monthly vehicle sales data was obtained; no Texas-specific data was used. U.S. vehicle sales by month from April 2016 to April 2017 (as shown in Figure 5.116) are found on the Trading Economics website (Trading Economics, 2017). During the period from September to December, vehicles sales are obviously higher than in other months. December is the month with the highest vehicle sales. Sales usually decline in January and oscillate until August. It is believed that vehicle price is the major factor impacting the sales number of vehicles.

Figure 5.116: U.S. Motor Vehicle Sales by Month

5.7.9 Daily Truck Trip Assignment

Motor vehicle movements do not vary significantly by month in general, but December does show slightly more movement due to the higher number of year-end sales. The daily motor vehicle truck trips in December is calculated using the method described in Section 4.5.3 and the results are as follows:

- Annual truck trips: 132,112
- Peak month: December
- Peak month percentage: 8.8%
- Peak month daily truck trips: 530

Figure 5.117 shows the assignment results of motor vehicles in December. It looks very similar to what was obtained in the original traffic assignment without considering the impact of congestion (see Figure 5.113). Some differences can observed, though. For example, the auto vehicles shipped to south border cities such as the city of McAllen used to mainly come from automotive ramps located near San Antonio along US 281, while the new analysis results show that most now come from automotive ramps located near Houston over US 77. This could be caused by the different travel times along these two routes. More secondary freight routes are used in the West Texas area due to longer travel times along those major freight corridors.

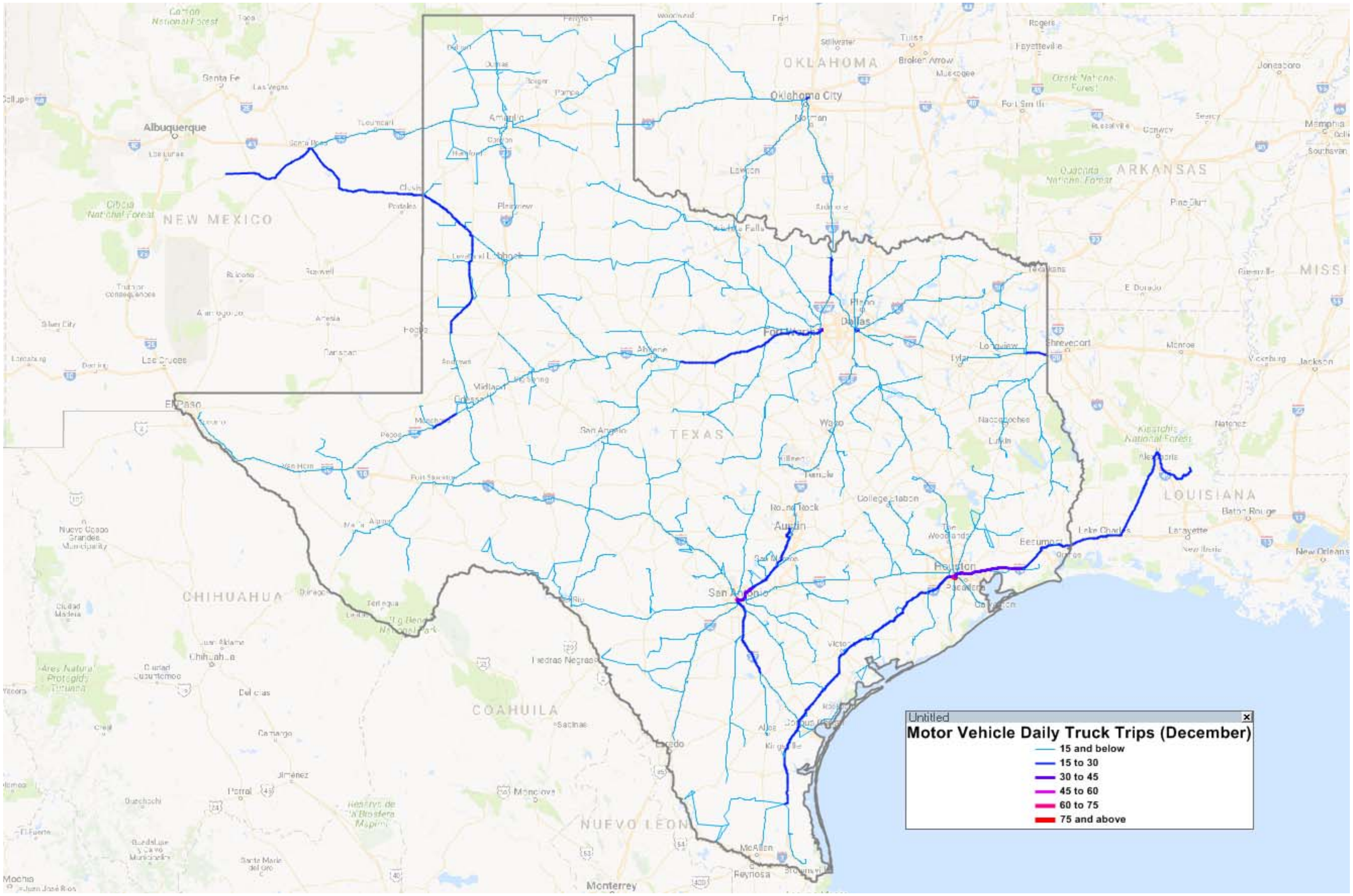


Figure 5.117: Motor Vehicles Daily Truck Trips in December

5.7.10 Summary

The motor vehicle industry continues to add new vehicles to our highway system every year. Once produced at an assembly plant, most vehicles are shipped by rail to automotive ramps, where they are offloaded and trucked to nearby dealerships. This modeling effort relied heavily on the 2010 STB Waybill Sample to estimate the number of vehicles offloaded at each automotive ramp in Texas and also to estimate (by default) the number of vehicles shipped by truck from the automotive assembly plants within the state. The number of motor vehicle attractions in each county relied on dealership information from the TWC and TxDMV and averaged this data with county population estimates to provide a reasonable estimate. The modeling methodology could be further improved by obtaining exact production and sales numbers from a non-public, paid subscription data service, such as WardsAuto.

Motor vehicle movements concentrate around the major population centers in Texas. Vehicle movements in western Texas counties appear to traverse greater distances between automotive ramps and dealerships due to a lack of automotive ramps in West Texas. However, since the demand is significantly less than the major population centers in East Texas, these longer truck shipments are anticipated.

This study estimates the annual motor vehicle truck trips at about 130,354. This figure is quite close to the number estimated by the Transearch database, which is about 136,968. The large number of motor vehicle trucks moving on IH 35 shown in Transearch results but not in our estimated results could be caused by the exclusion of import, export, and pass-through trips that are not originating or ending in Texas.

Motor vehicles sales usually are higher in December, potentially causing higher demand for motor vehicle transportation from assembly plants to dealerships in that month.

5.8 Electronics

5.8.1 Background

The electronics commodity group is categorized by high-value, low-weight products, unlike many other commodity groups under consideration here (e.g., agriculture, gasoline, etc.). The growth of the electronics industry is skyrocketing due to increased production of computers, cell phones, televisions, and other items. These products are increasingly produced outside the United States.

More electronics are transported by air than by rail or water, particularly as compared to other commodities. A high frequency of urban truck trips to/from airports is anticipated for the first-mile/last-mile journey. Additionally, there is a high frequency of truck transport to/from Mexico, a top trading partner in this study. According to the Transborder database, nearly $26 billion in electronics were imported from Mexico at Texas land crossings and over $36 billion was exported (USDOT Bureau of Transportation Statistics, 2016). Figure 5.118 shows a map of the Texas-Mexico land border crossings. Much of the truck traffic crosses the border in Laredo and El Paso.

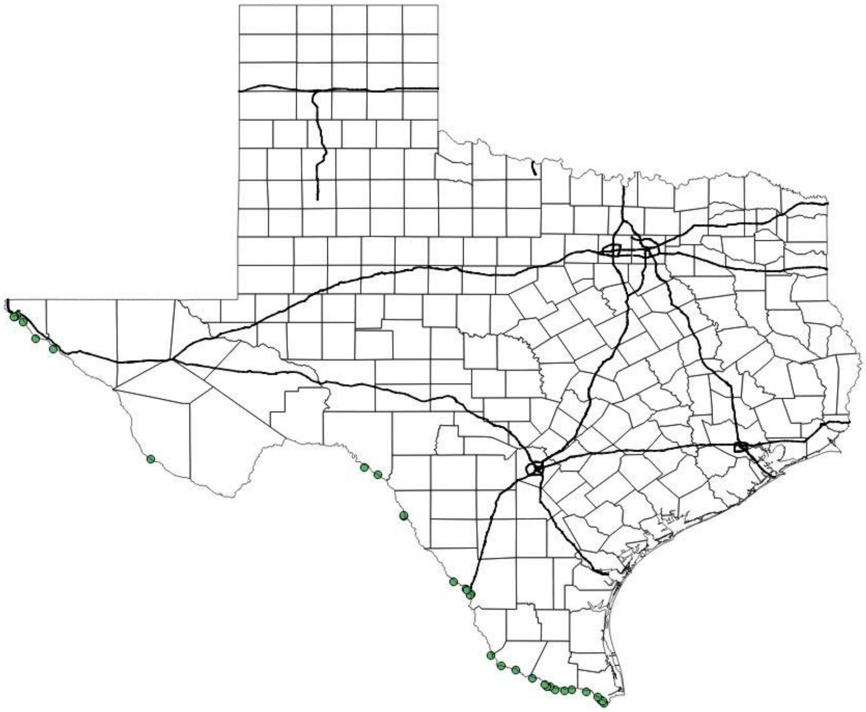


Figure 5.118: Texas-Mexico Land Border Crossings

5.8.2 Supply Chain

Since the overall electronics flow is very difficult to capture and model due to the increased use of air transportation throughout various steps of the supply chain (urban truck trips would dominant commodity flow), the modeling methodology for electronics will focus on US-Mexico electronics flow using trucks through the Texas border entry/exit locations. Manufacturing facilities dominate trip productions while consumption/population in the United States and Texas dominate trip attractions.

5.8.3 Datasets

The following free public data sources were used in this modeling effort:

- TWC Data – electronics manufacturing facilities, sorted by NAICS.
- US Census Resident Population Data – included to calculate state-level and county-level trip attractions (United States Census Bureau, n.d.).
- USDOT Bureau of Transportation Statistics Transborder Data – import and export data was drawn from this database (USDOT Bureau of Transportation Statistics, 2016).

Table 5.23 presents the NAICS codes of electronics manufacturing and retail facilities. Additionally, the Transborder commodity code for electronics is included as a crosswalk (USDOT Bureau of Transportation Statistics, 2016).

Table 5.23: Industry codes for electronics

2012 NAICS Code	*Category*	*Transborder Commodity Code*	*Category*
334	*Computer and Electronic Product Manufacturing*	*85*	*Electronic machinery and equipment and parts thereof; Sound recorders and reproducers, television image and sound recorders and producers, and parts and accessories of such articles*
335	*Electrical Equipment, Appliance, and Component Manufacturing*		
443	*Electronics and Appliance Stores*		

5.8.4 Commodity Flow Estimation

The total truck imports and exports through Texas-Mexico land border crossings were drawn from the Transborder database for the full year 2014. The dollar values of these electronics movements are summarized in Table 5.24. Eleven of the land crossings included data for electronics imports or exports, three of which are in or near El Paso. Laredo and El Paso were by far the top two land border crossings in 2014 for both electronics imports and exports.

Table 5.24: Total truck imports and exports

Port Code	Port Name	County	2014 Truck Exports ($)	2014 Truck Imports ($)
2301	Brownsville	Cameron	$1,650,861,605.00	$2,137,519,185.00
2309	Progresso	Hidalgo	$3,267,288.00	–
2305	Hidalgo	Hidalgo	$3,049,173,648.00	$6,897,197,881.00
2307	Rio Grande City	Starr	$148,265.00	$485,442.00
2310	Roma	Starr	$5,483,215.00	$1,465,707.00
2304	Laredo	Webb	$11,190,858,961.00	$15,149,844,069.00
2303	Eagle Pass	Maverick	$468,887,559.00	$846,089,324.00
2302	Del Rio	Val Verde	$378,995,735.00	$591,825,865.00
2403	Presidio	Presidio	$7,236,943.00	–
2404	Fabens	El Paso	$288,509.00	–
2402	El Paso	El Paso	$9,079,179,870.00	$10,642,019,382.00
			$25,834,381,598.00	**$36,266,446,855.00**

Included within this data is a large value of electronics that does not have a destination within Texas. It is estimated that only 28% of the total imports through Laredo stay within Texas (USDOT Bureau of Transportation Statistics, 2009). Based on this estimate of imports into Texas from Laredo, a gravity model was created and calibrated using the population of each US state as an attraction and the shortest time path distance (in miles) from Laredo to each state's highest population center as a friction factor. For Hawaii, the distance was calculated as the road distance to Los Angeles and then the straight line distance from Los Angeles to Honolulu.

For the population center in Texas, the location was flexible to ensure that 28% of the products passing through Texas land border crossings remained within the state. The Texas center was constrained geographically by the Texas Triangle bounded by IH 35 to the west, IH 45 to the north and east and IH 10 to the south. Since the same population center locations would be used for El Paso in the next model, the Texas location was to be located as far west as possible within the triangle.

After several runs of the model, a geographic center located in Temple, Texas proved to be the optimal location. This location is feasible since it is situated approximately halfway between the major population centers of San Antonio and Dallas-Fort Worth on IH 35. The gravity model calculations were repeated by replacing Laredo with El Paso. The El Paso gravity model ensured that 17% of the truck shipments through El Paso remained within Texas.

The percentages of movements to/from each state calculated by the Laredo model were applied to the eight border crossings between Del Rio and Brownsville. The percentages of movements to/from each state calculated by the El Paso model were applied to the El Paso, Fabens, and Presidio border crossings.

For the shipments remaining with Texas, the electronics imports were distributed to all 254 Texas counties using population as the attraction. The electronics exports were allocated proportionally to Texas counties with at least one manufacturing facility (NAICS Codes 334-335) identified within the TWC data.

5.8.5 Transportation

Truck Type

Since electronics are a high-value, low-weight commodity, a greater share is transported by air than by rail or water. For the truck trips through the land border crossings in Texas, electronics can be transported in any type of box truck or box trailer. A traditional five-axle truck tractor with 53-ft box trailer (Figure 5.119) is most often used to transport electronics across the Texas-Mexico border, as this type of truck can provide the volume required to move a large amount of products. Two 28.5-ft trailers can also be attached to the truck tractor for a different six-axle configuration (Figure 5.120). This turnpike double configuration is readily used by shipment companies such as FedEx and UPS.

Figure 5.119: Truck Tractor with 53-ft Box Trailer

Figure 5.120: Truck Tractor with Turnpike Double Trailers

Truck Capacity

Since electronics are high-value, low-weight products, the truck capacity is often boxed out before maxing out the weight. The trucks will be limited by the volume of electronics products. These products may be boxed with an abundance of packaging materials, further limiting the potential area within the truck. Due to the large volume capacity requirements, these electronics shipments will use larger traditional box trailers.

Converting Value to Equivalent Trucks

The value of electronics products cannot be assigned to truck trips because it cannot be determined how many electronics products a certain truck may carry. A truck (such as those pictured in Figure 5.119 and Figure 5.120) may carry many different commodities or may be entirely filled with electronics. Based on the data provided by the Bureau of Transportation Statistics' Transborder database, the amount of trucks used to carry the electronics products across the border cannot be determined.

Estimating Empty Trucks

Since electronics are carried in larger box trailers for the longer haul trips across the Texas-Mexico border, it is anticipated that these trailers will be utilized for transport of other goods and materials back across the border or to other locations once their loads have been dropped off. It cannot be determined whether these shipments will include electronics products. However, if a truck drops off electronics products at an electronics manufacturing facility, it will most likely be used to transport the next step of the product.

5.8.6 Network Analysis

The value of electronics transported across the Texas-Mexico border was obtained directly from the Transborder database and it is really hard to estimate how many trucks needed to carry those electronics, a truck trip matrix was not prepared in the previous section. The value of electronics shipments was assigned directly to the created freight network. The results are shown in Figure 5.121.

Laredo and El Paso have the largest amounts of Transborder-recorded shipments, so the flow of electronics is especially concentrated near these border crossings. Additionally, since only a small percentage of imports/exports from Laredo remain in the state of Texas, and an even smaller percentage from El Paso, flow is especially concentrated on interstate highways. The largest value of transported electronics, more than $24 billion per year, is seen on the stretch of IH 35 between Laredo and San Antonio. IH 10 between Houston and the Louisiana border, IH 20 between IH 10 and Midland-Odessa, and IH 35 between San Antonio and the DFW Metroplex also have high values of shipments.

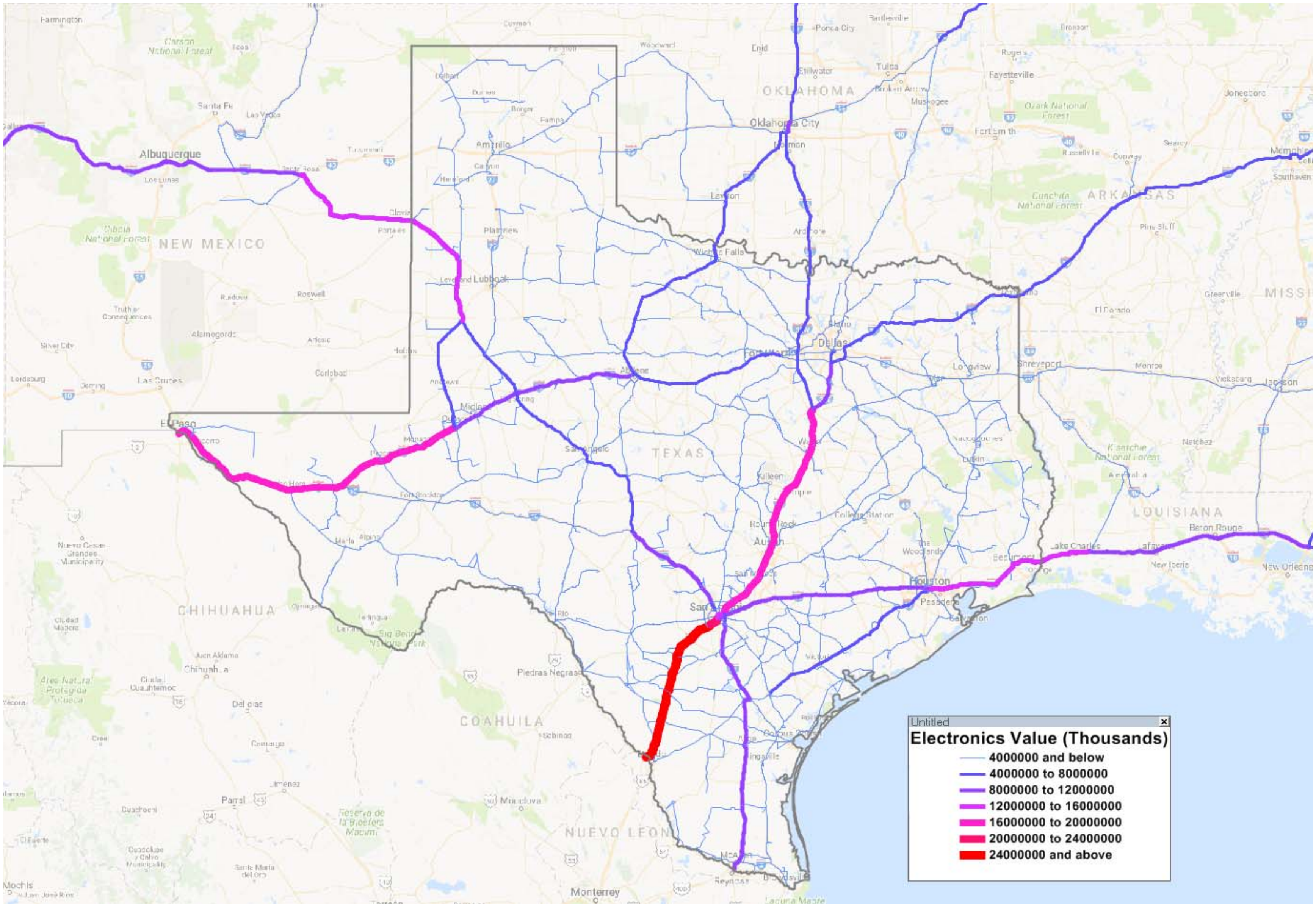


Figure 5.121: Electronics Value

5.8.7 Compare with Transearch Data

As shown in Table 4.1, the closest commodity category to electronics in the Transearch database is electric equipment (STCC 36). The research team processed the electric equipment data in Transearch based on the procedure described in Section 4.4.2 and assigned it to the freight network created in Section 4.3.1. The assignment results are shown in Figure 5.122.

According to Transearch data, most of the electrical equipment within Texas is moving on the Texas Triangle[17] corridors. The section of IH 35 between Dallas and Austin carry the highest value of electrical equipment. In this project, only electronics imported from México were modelled; therefore, a direct comparison is not possible.

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[17] The Texas Triangle is formed by the three main cities—Houston, Dallas, and San Antonio—connected by a highway system of Interstate 45, Interstate 10, and Interstate 35.

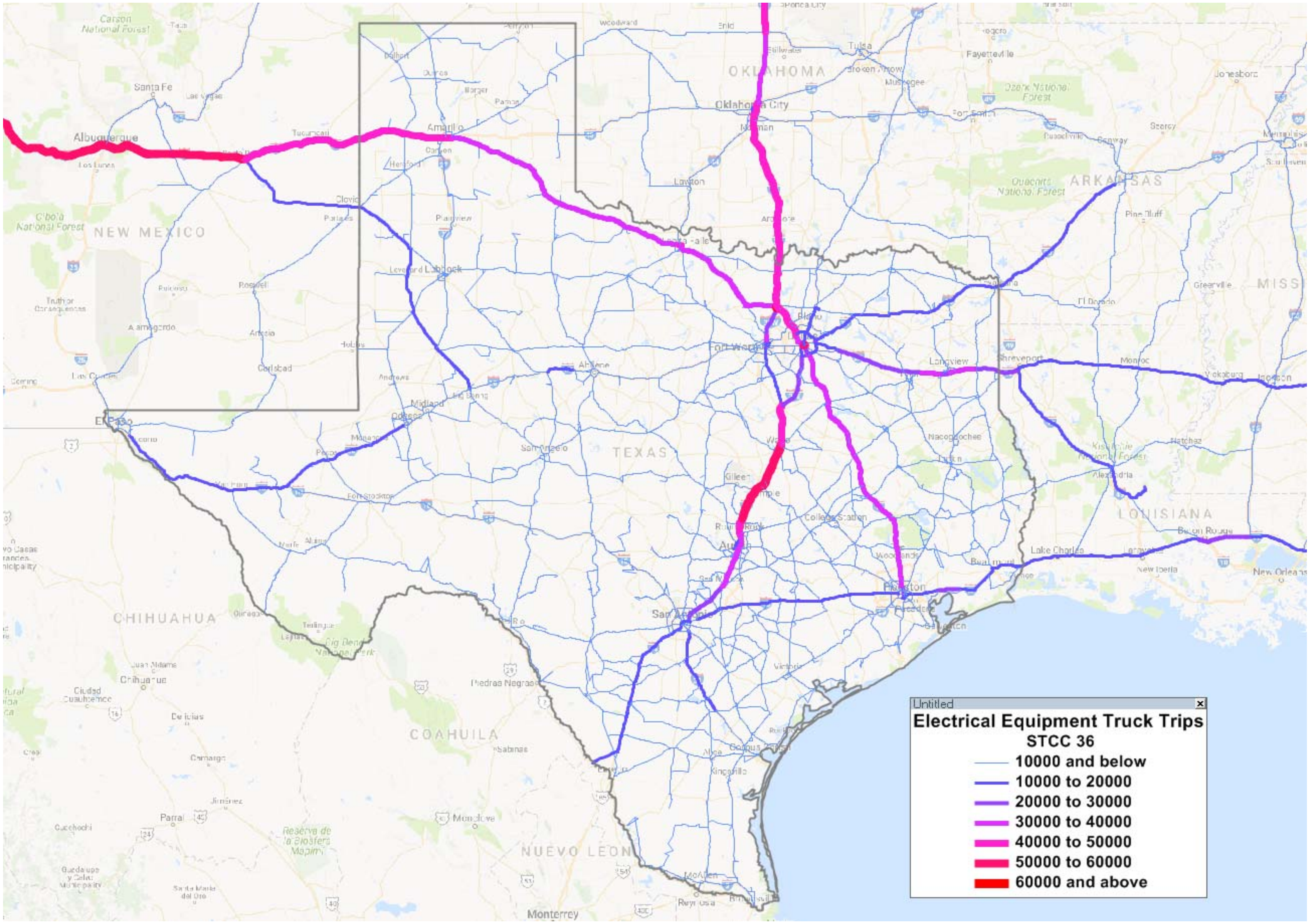
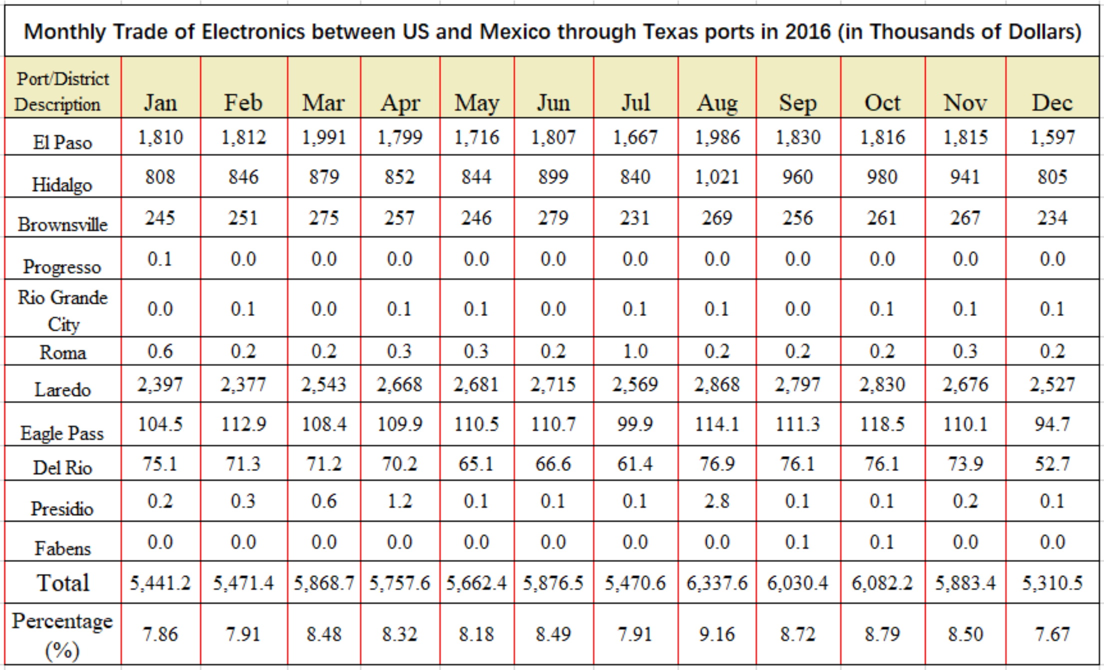


Figure 5.122: Transearch Electrical Equipment Value

5.8.8 Seasonal Variation

Monthly trade data for electronics was obtained from the USDOT Bureau of Transportation Statistics Transborder Database (USDOT Bureau of Transportation Statistics, 2016). Based on the Transborder Database, eleven land ports in Texas are mainly used for exporting or importing of electronics between the U.S. and Mexico (as shown in the Figure 5.123). Monthly electronics trade data from those eleven ports in 2016 was collected, with the monthly percentages shown in Figure 5.124, where from January to July, the total trade of electronics through the Texas border is relatively constant. There is a spike in August, after which the total trade begins to decrease rapidly in October and through the end of the year.

The statistic result is $X^2 = 20.08$, which is much larger than the critical value. ($X^2 = 20.08 > X_t^2 = 5.58$). This could be caused by the spike in August and the rapid drop later in the year. The seasonal variation of the movement of trucks carrying electronics and crossing the Texas-Mexico border therefore warrants consideration in commodity flow models.



Monthly Trade of Electronics between US and Mexico through Texas ports in 2016 (in Thousands of Dollars)

Port/District Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
El Paso	1,810	1,812	1,991	1,799	1,716	1,807	1,667	1,986	1,830	1,816	1,815	1,597
Hidalgo	808	846	879	852	844	899	840	1,021	960	980	941	805
Brownsville	245	251	275	257	246	279	231	269	256	261	267	234
Progresso	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rio Grande City	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1
Roma	0.6	0.2	0.2	0.3	0.3	0.2	1.0	0.2	0.2	0.2	0.3	0.2
Laredo	2,397	2,377	2,543	2,668	2,681	2,715	2,569	2,868	2,797	2,830	2,676	2,527
Eagle Pass	104.5	112.9	108.4	109.9	110.5	110.7	99.9	114.1	111.3	118.5	110.1	94.7
Del Rio	75.1	71.3	71.2	70.2	65.1	66.6	61.4	76.9	76.1	76.1	73.9	52.7
Presidio	0.2	0.3	0.6	1.2	0.1	0.1	0.1	2.8	0.1	0.1	0.2	0.1
Fabens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Total	5,441.2	5,471.4	5,868.7	5,757.6	5,662.4	5,876.5	5,470.6	6,337.6	6,030.4	6,082.2	5,883.4	5,310.5
Percentage (%)	7.86	7.91	8.48	8.32	8.18	8.49	7.91	9.16	8.72	8.79	8.50	7.67

Figure 5.123: Monthly Trade of Electronics between U.S. and Mexico through Texas Ports in 2016

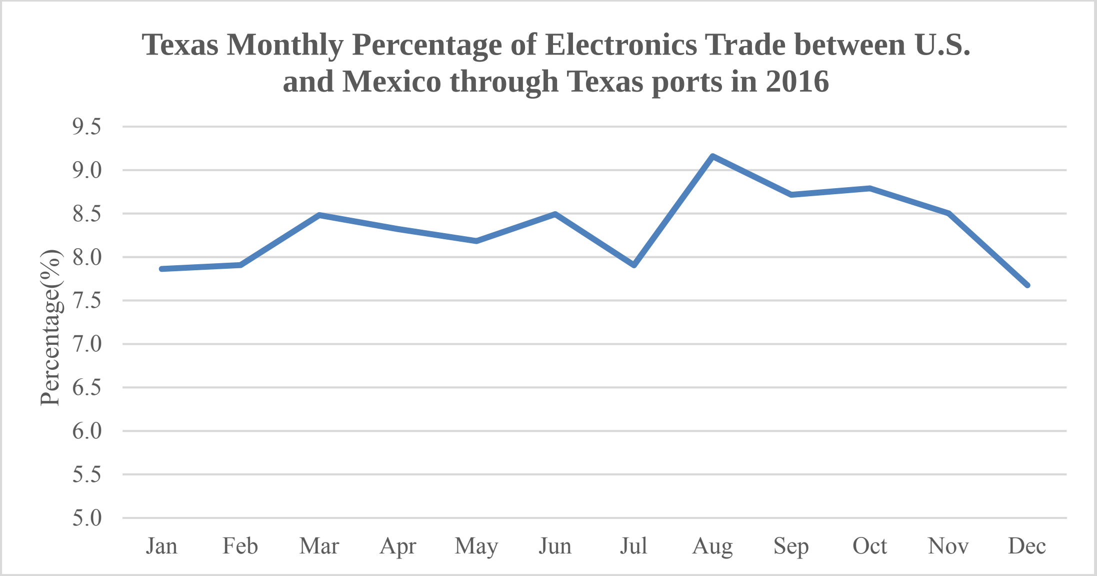


Figure 5.124: Texas Monthly Percentage of Electronics Trade between U.S. and Mexico through Texas Ports in 2016

5.8.9 Daily Value Assignment

According to Transborder data, the movement of electronics across the Texas-Mexico border is slightly higher in August. The daily value of electronics across the Texas-Mexico border in August is calculated using the method described in Section 4.5.3 and the results are as follows:

- Annual value: $62,100,828,000
- Peak month: August
- Peak month percentage: 9.2%
- Peak month daily truck trips: $247,305

Since electronics were estimated only in dollar values (not number of truck trips), they cannot be assigned to the network using the capacity-based BPR function (see second part of Section 4.5.2). Therefore, the all-or-nothing method was still used for assigning electronics. However, the congested travel time was used in the all-all-nothing traffic assignment rather than free-flow travel time as in the original traffic assignment described in Section 5.8.6. The results are shown in Figure 5.125.

Even though the assignment used congested rather than free-flow travel times, the overall pattern is very similar to what estimated in the original traffic assignment (see Figure 5.121). The flow pattern shown in Figure 5.125 uses more roadways, though, especially those roadways on the secondary freight network. This could also be the result of congestion’s impact.

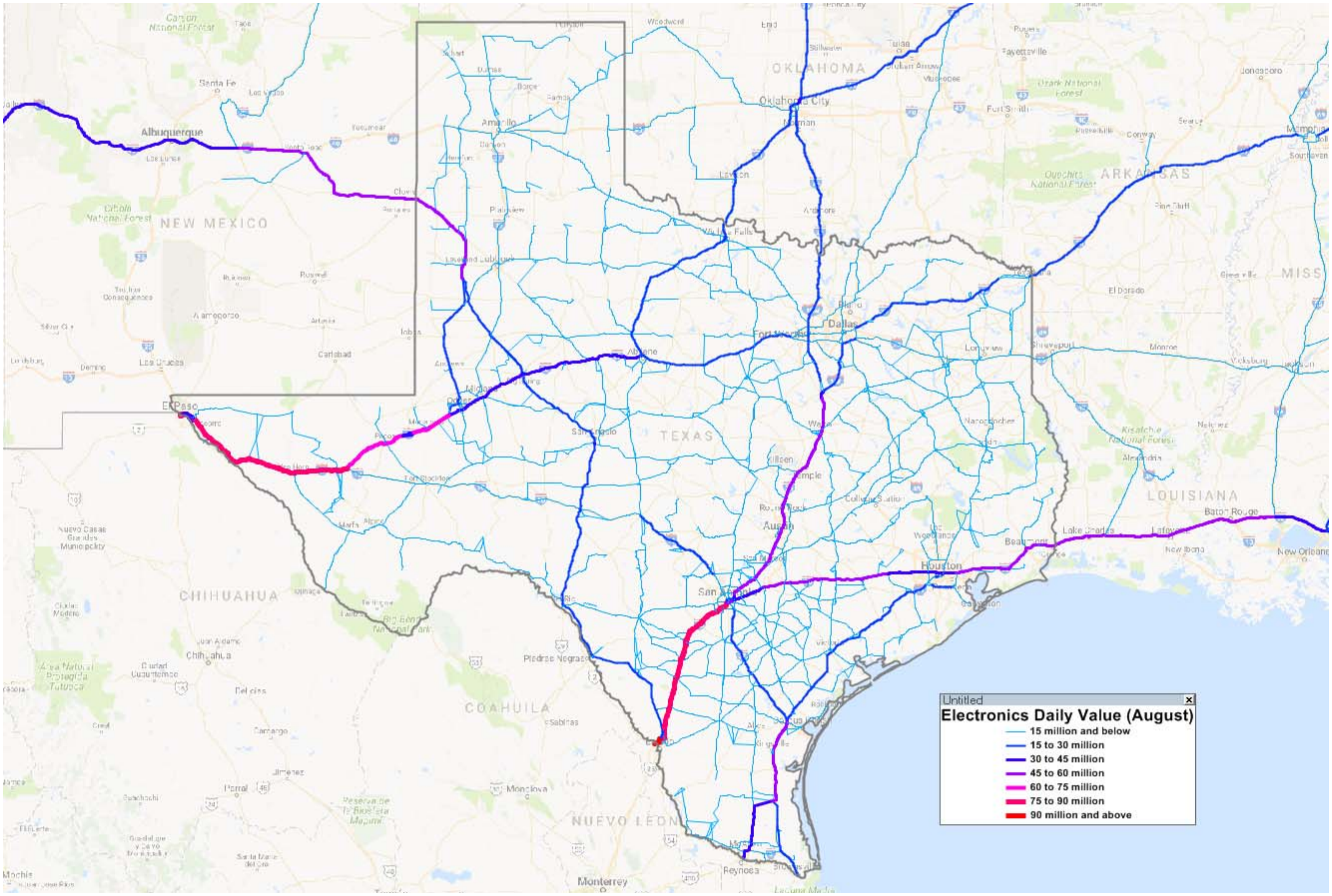


Figure 5.125: Electronics Daily Value in August

5.8.10 Summary

The electronics industry continues to grow as the demand for new and innovative electronics products rises. The electronics supply chain is long and complicated, involving worldwide suppliers and manufacturers striving to market and sell products as quickly as they are developed, so air travel is favored over the traditional but slow rail and water modes. Trucking still plays a major part in this industry, but trips are often limited to urban travel to the nearest freight airport.

This modeling effort utilized Transborder truck shipment data to estimate the flow of long-range truck trips through eleven Texas land border crossings. Using estimates published by the USDOT Bureau of Transportation Statistics, the shipments were allocated to US states and the District of Columbia. Within Texas, shipments (especially exports to Mexico) were concentrated around major population centers where manufacturing facilities and retail locations are focused.

Due to the different modeling target, it is hard to draw a fair comparison between the network flow patterns developed in this project and those estimated by the Transearch database. However, the results obtained in this study are believed to be reliable, as the electronics trips are limited to those crossing the Texas-Mexico border and estimated directly based on the TransBorder database.

The shipment of electronics crossing the Mexico-Texas border shows slight seasonal variation with a peak in the August.

5.9 Plastic and Rubber

5.9.1 Background

The plastic and rubber industry is one of the most important in Texas. In 2014, the value of shipment of Texas plastic and rubber manufacturing ranked No. 3 in the US and the total number of employees ranked No. 4. (Texas Economic Development Corporation, 2016a).

The plastic and rubber products manufacturing industry makes goods by processing plastics materials and raw rubber, either natural or synthetic (Texas Economic Development Corporation, 2016a). The resin manufacturing industry includes establishments that produce plastic resins, synthetic rubber, and synthetic fibers. The products of the resin manufacturing industry are the base materials for plastic and rubber manufacturing (Texas Economic Development Corporation, 2016b).

The plastic and rubber products manufacturing industry is concentrated along the Gulf Coast as well as in north and central Texas (Texas Economic Development Corporation, 2016a). The resin manufacturing industry is highly concentrated along the Gulf Coast near Houston and Beaumont/Port Arthur (Texas Economic Development Corporation, 2016b).

In 2014, Texas plastic resin exports were valued at \$14.7 billion (Texas Economic Development Corporation, 2016b). Texas plastic and rubber products exports were valued at \$5.2 billion. Plastic and rubber manufacturing was Texas' 11th largest export sector. Top plastic and rubber commodities shipped from Texas ports include plastic containers and tires (Texas Economic Development Corporation, 2016a). The top export markets for resin and plastic and rubber products are listed in Table 5.25.

Table 5.25: Top export markets (Texas Economic Development Corporation, 2016a, b)

Plastic Resin	Plastic and Rubber Products
Mexico (38%)	Mexico (87%)
Canada (22%)	Canada (10%)
China (14%)	China (1%)
Belgium (11%)	Brazil (1%)
Brazil (10%)	Australia (1%)
Columbia (5%)	Japan (1%)

According to TxDOT's 2014 *Texas Port Report*, resins and plastics are the top commodities exported from the Port of Houston and resins are the top commodity exported and imported from the Port of Freeport.

Port of Houston

Oil refineries, resin manufacturers, and plastic and rubber manufacturers are concentrated in Houston. Because of the short distance from those manufacturers to the Port of Houston, and because the Port of Houston used to be the only port of loading for container ships, the majority of plastic resin, plastic, and rubber products are exported from that port. The Port of Houston provided the research team their 2015 plastic and resin export data. From January through December 2015, 3,608,792 tons of plastics and resins (based on commodity description from PIERS Journal of Commerce) were exported from the Port of Houston. Figure 5.126 shows their top 10 plastics and resins export trading partners.

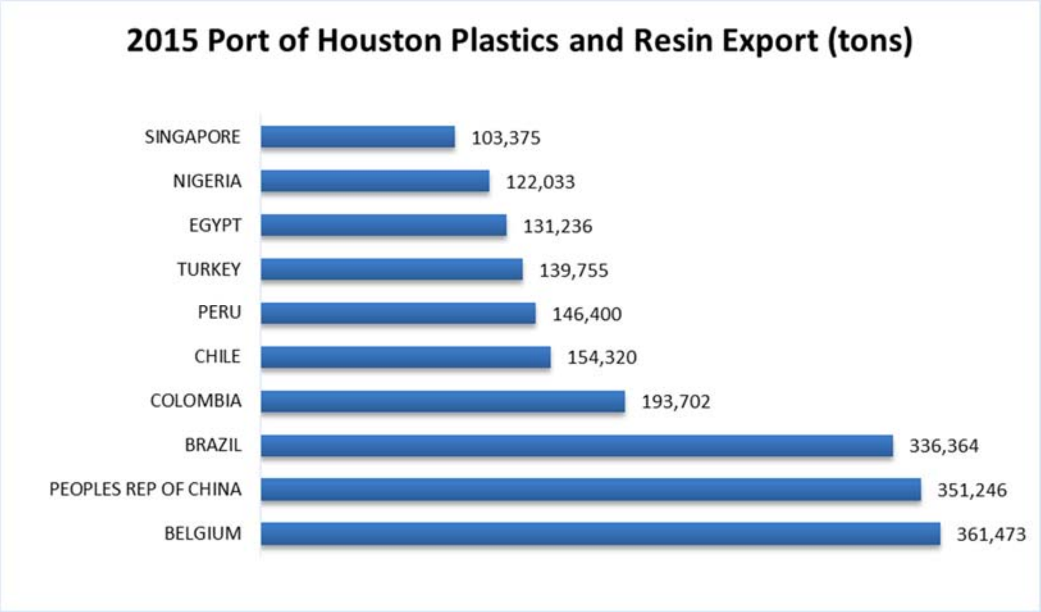


Figure 5.126: Top 10 Plastics and Resins Export Trading Partners of Port of Houston in 2015

Port of Freeport

According to the Port of Freeport's Director of Economic Development Mike Wilson (2016), the majority of the resins manufactured in Freeport are now moving through the Port of Houston. That's because Port of Freeport opened their container terminal and added a global carrier to their list of container services only a year ago. Last year the Port of Freeport processed about 126,000 tons—mostly import fruit and export chemicals (resins) to and from Central America, Africa, and the Middle East. Given that several major resin manufacturers (such as Dow Chemical, BASF, and Shintech) are only 3–4 miles away from the Port of Freeport, their 6 billion pounds of product will likely start moving through Freeport more and more over time.

5.9.2 Supply chain

Although crude oil is a source of raw material (feedstock) for making plastics, it is not the major feedstock for plastics production in the United States. Plastics are produced from natural gas, feedstocks derived from natural gas processing, and feedstocks derived from crude oil refining.

Natural gas is used for process heat in the production of precursor chemicals and plastics and as a feedstock for those precursor chemicals. Petrochemical feedstock naphtha and other oils refined from crude oil are used as feedstock for petrochemical crackers that produce the basic building blocks for making plastics. However, the primary feedstock for U.S. petrochemical crackers are hydrocarbon gas liquids (HGL), of which 82% were byproducts of natural gas processing in 2014. The remaining 18% of the HGL were produced by U.S. refineries and contain both alkanes and olefins. Alkanes can be used as feedstock for petrochemical crackers, whereas refinery olefins, primarily propylene but also minor quantities of ethylene and butylenes, can be used as direct inputs into plastics manufacturing (US EIA).

Petrochemical feedstock such as naphtha, ethane, propane and butane are usually transported through pipeline or by barge to a petro-chemical plant where a thermal splitting process called cracking breaks them down into smaller hydrocarbon molecules such as ethylene, propylene, and butylene. These smaller hydrocarbon molecules are further processed to form different types of polymers. These plastic polymers are also referred to as resin products. Commonly known resin products include polypropylene, polyethylene, elastomers, synthetic rubber, rayon, acetate, polyester, nylon, and other polyolefin resins.

Using injection molding, casting, compression molding, or other manufacturing processes, the raw resin materials and raw rubbers are further processed at plastic/rubber manufacturing facilities to make goods that are typically for intermediate or final consumption. For example, plastic products include bags, packing materials, films, pipes, foam, bottles, and other items. Rubber products include tires, hoses, belts, and other products.

Figure 5.127 shows the components of plastic and rubber supply chain described above and their corresponding NAICS code.

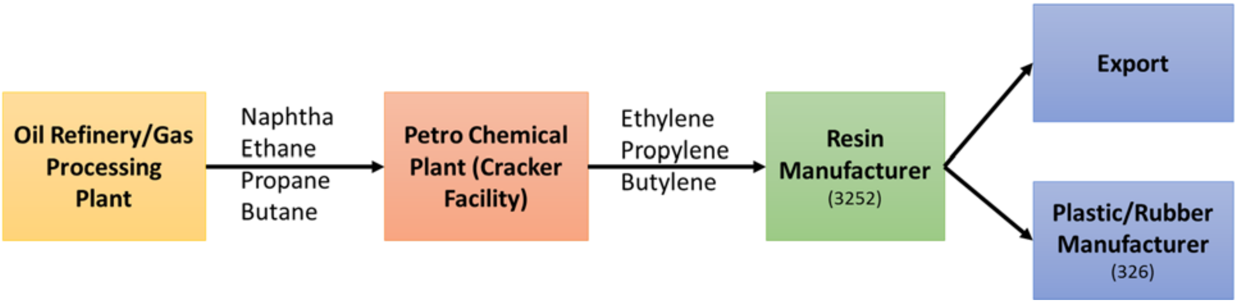


Figure 5.127: Plastic/Rubber Supply Chain

The EIA (2016a) provides the time history data of refinery & blender net production of naphtha, ethane, propane, butane, ethylene, propylene, and butylene in the Texas Inland and Texas Gulf Coast districts[18] from 1993 to 2015. The 2015 data are shown in Table 5.26.

Table 5.26: 2015 refinery & blender net production (annual-thousand barrels)

	Product	**Texas Inland**	**Texas Gulf Coast**
Petro-chemical feedstock	Ethane	15	1,691
	Propane	2,832	29,237
	Normal Butane	773	15,188
	Naphtha for Petrochemical Feedstock Use	1,243	45,471
Hydrocarbon molecules	Ethylene	N/A	129
	Propylene	4,519	38,282
	Butylene	0	-3,317

However, as described above, most of these products are transported by pipeline rather than highway network. Therefore, this section of study is focused on the last segment of the supply chain, the transportation of plastic resin.

Figure 5.128 shows the supply chain and transportation mode of plastic resin after it is manufactured. Plastic resins are shipped by rail from their manufacturers to rail terminals for storage and then packaged at bagger facilities.

Resin exported through West Coast ports is either 1) moved by rail to bagger facilities located in California near those ports and then transported by container trucks to the port, or 2) moved by rail to bagger facilities in Texas and then transported by rail to West Coast ports directly (e.g., the “Dallas-to-Dock” plastic resin shipping services provided by Union Pacific).

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[18] Based on the Petroleum Administration for Defense district descriptions and maps (US Energy Information Administration, 2016b), Texas Gulf Coast district includes the following Texas counties: Newton, Orange, Jefferson, Jasper, Tyler, Hardin, Liberty, Chambers, Polk, San Jacinto, Montgomery, Harris, Galveston, Waller, Fort Bend, Brazoria, Wharton, Matagorda, Jackson, Victoria, Calhoun, Refugio, Aransas, San Patricio, Nueces, Kleberg, Kenedy, Willacy, and Cameron. The remainder of Texas is Texas Inland.

- Resin exported through Texas ports is moved by rail to bagger facilities in Texas, mainly those near the Port of Houston, and then transported by container trucks to that port.
- Resin consumed domestically will be packaged at bagger facilities, then moved either by rail or by truck. The truck types most commonly used for transporting plastic resin are dry bulk trucks and box van trucks.

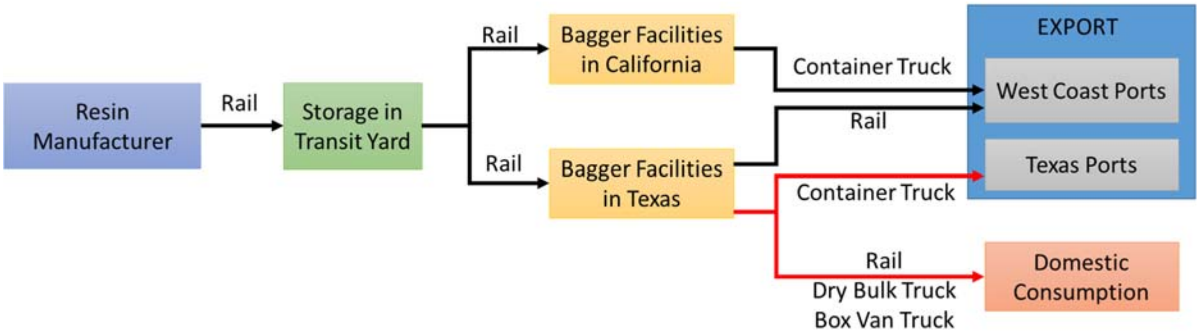

Figure 5.128: Movement of Plastic Resin

As this study is focused on the Texas roadway system, rail shipment and any shipping activity outside of Texas will not be considered. The discussion hereafter will be focused on the segment of the logistic chain between packagers in Texas and at Texas ports and other domestic users (represented by red arrows in Figure 5.128).

5.9.3 Datasets

TWC data provide useful information about resin manufacturers and plastic/rubber manufacturers, sorted by NAICS code.

- Resin manufacturers are those companies associated with NAICS code 3252.[19] Figure 5.129 demonstrates resin manufacturer locations in Texas.
- Plastic and rubber manufacturers are those companies associated with NAICS code 326. It includes many types of businesses because of the wide range of plastic and rubber products. Figure 5.130 shows plastic and rubber manufacturers' locations in Texas.

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[19] This category includes three types of businesses: Plastics Material and Resin Manufacturing (325211), Synthetic Rubber Manufacturing (325212), and Artificial and Synthetic Fibers and Filaments Manufacturing (325220).

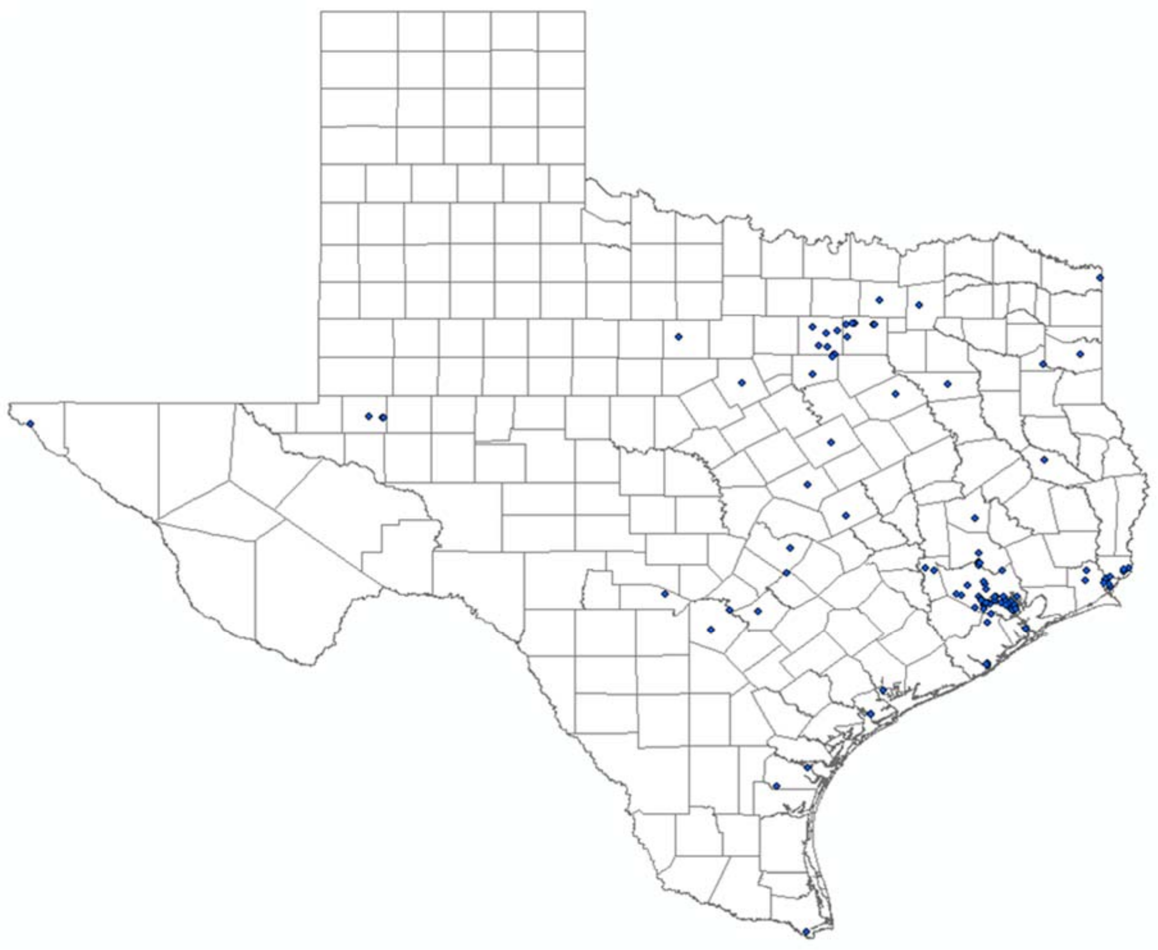

Figure 5.129: TWC Data Resin Manufacturer Locations

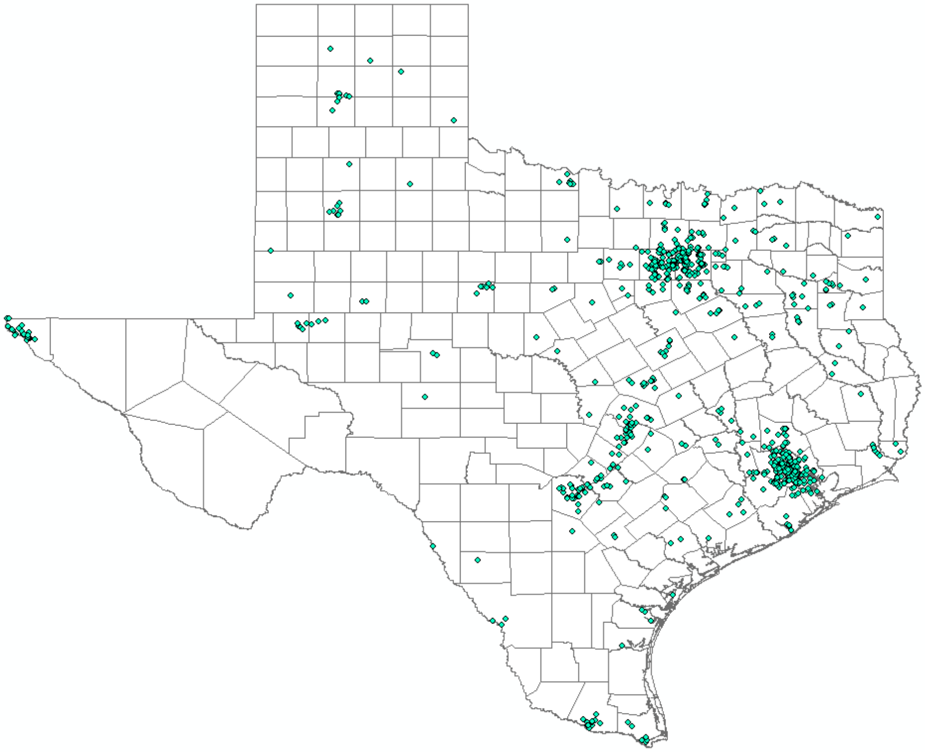

Figure 5.130: TWC Data Plastic and Rubber Manufacturer Locations

According to the statistics developed by Texas Economic Development Corporation (2016a), in 2014, the total value of shipment of the Texas Resin Manufacturing industry is $43 billion, among which $14.7 billion were exported to other countries. This value can be used in the modeling process to estimate the production of resins.

5.9.4 Commodity Flow Estimation

Export

As mentioned above, in 2014, Texas plastic resin total production had a $43 billion value of shipment, of which $14.7 billion was exported. Assuming the price of plastic resin is about $820 per ton (American Chemistry Council, 2013), then Texas total plastic resin production in 2014 was about 52.4 million tons, with about 17.9 million tons exported.

Based on Furneaux (2014), the Port of Houston exported 244, 812 twenty-foot equivalent units of plastic resin in 2014. The maximum payload of a standard 20 ft. standard container is 48,325 lbs. So, the total export from Port of Houston in 2014 was about 11.8 billion lbs (5.9 million tons). In other words, among all the plastic resin produced in Texas in 2014, 12 million tons were exported from the West Coast ports and 5.9 million tons were exported from Port of Houston.

No direct information can be found indicating the location and size of all plastic resin packagers in Texas. However, it is reasonable to assume most packagers are located near rail terminals. For example, Packwell, a leading Gulf Coast resin packager, and BNSF have agreed on a framework for construction of a new plastics export packaging facility in the rail-connected Alliance Westport industrial sector located in north Fort Worth, Texas (Worrell, 2016).

Rail terminals near the Port of Houston are shown in Figure 5.131 (IANA, 2016). The Union Pacific terminal located at Barbours Cut can provide service directly to the docks. Plastic resin arriving at the other three rail terminals needs to be put into oceangoing containers and transported by truck to the Port of Houston.

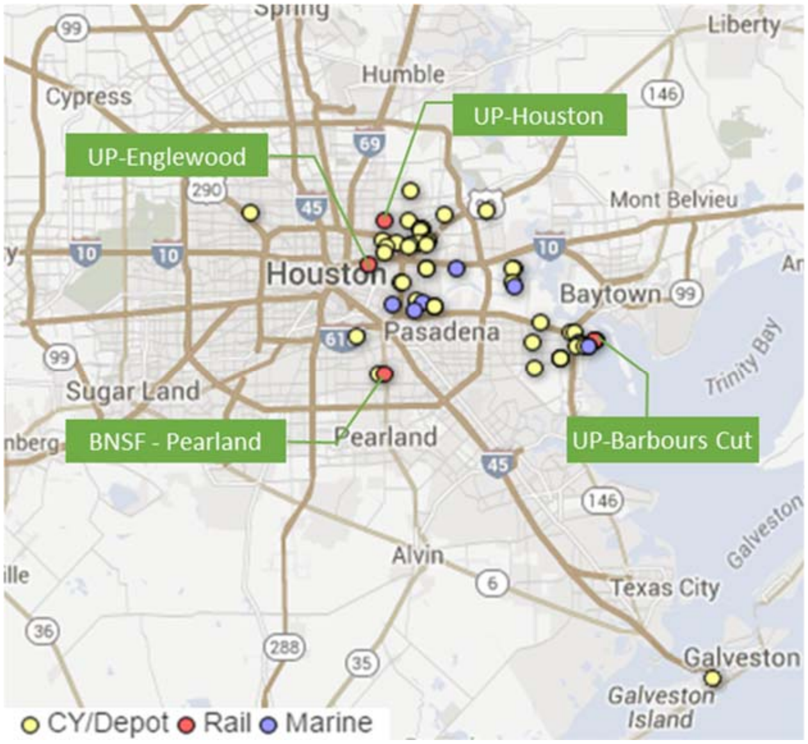

Figure 5.131: Rail Terminals near the Port of Houston

These container trucks are most likely to travel on the eastern portion of the IH-610 loop, SH 225, and SH 8 between US 90 and IH 45 (see Figure 5.132). As no information is available regarding how much of the plastic resin exported through Port of Houston is transported from those three terminals to the Port of Houston, an exact value of plastic resin moved on those routes is difficult to estimate.

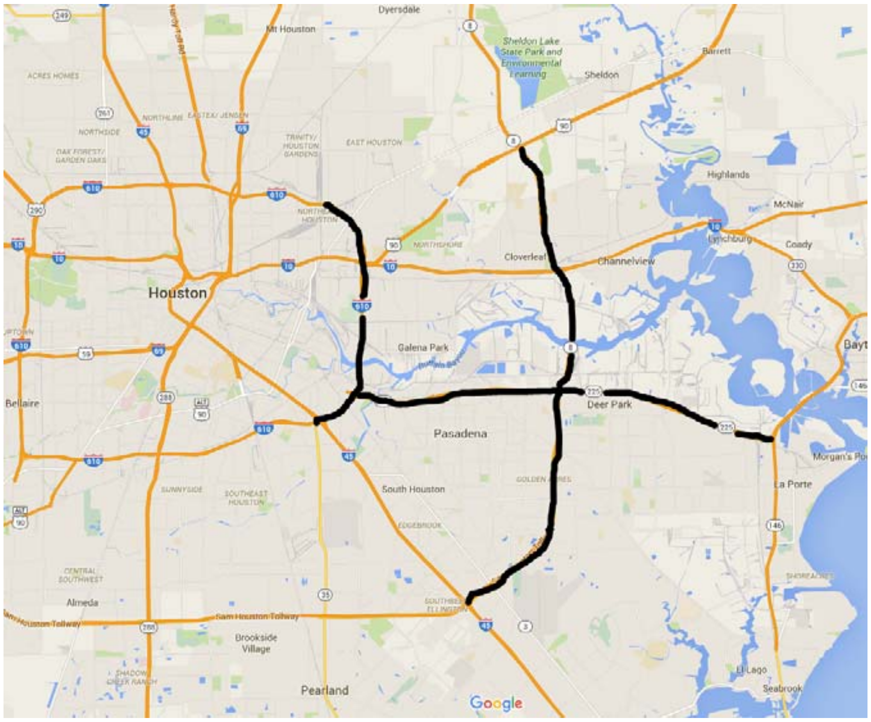

Figure 5.132: Routes with Heavy Plastic Resin Container Truck Volume near the Port of Houston

Domestic Consumption

As mentioned above, among $43 billion value of shipment of plastic resin produced in Texas in 2014, $28.3 billion value of shipment was consumed domestically. However, no information is available to indicate how much of that was consumed within Texas and how much was shipped to the other states. If information about how much of the $28.3 billion value of shipment was consumed within Texas is available, then the county-to-county flow matrix can be developed following these steps:

Resin Production at Resin Manufacturers

The data of county-level resin production in Texas is not readily available, but it can be estimated based on plastic resin consumption within Texas and each county's number of resin manufacturing employees. It is reasonable to assume that a county's ability to produce resin is proportional to its number of employees in the resin manufacturing industry. So, the production of resin products by each county can be calculated by multiplying the plastic resin consumption within Texas with the proportion of the county's resin manufacturing employee among all the counties. This results in the estimated county-level resin production[20].

Resin Products from Resin Manufacturers to Plastic and Rubber Manufactures

Even though the distribution of plastic and rubber manufacturers in Texas is much more dispersed compared to the resin manufacturers, mainly because of the large number and various

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[20] This is the production used for consumption within Texas.

types of companies in plastic and rubber business, there are some overlaps in terms of the concentration areas of the resin manufacturers and plastic and rubber manufactures. For example, in the Houston area and the Dallas area. Therefore, a large portion of resin flows within those areas are expected. To capture this intra-county flow, a facility-to-facility gravity model can be used to estimate the resin flow from resin manufacturers to plastic/rubber manufacturers. Specifically, the percentage of resin flow from one resin manufacturers to every plastic/rubber manufacturers is proportional to the number of employees of the resin manufacturer and the plastic/rubber manufacturer, and inversely proportional to the distance between those two facilities. Number of employees is a proxy of a facility's capacity and it is reasonable to assume distance as the impedance between the commodity flows between two facilities.

The facility-to-facility percentages can then be aggregated at the county level and normalized so that the sum of the percentage from one county to all the other counties is 100%. This aggregation is necessary as the production estimated in the previous step is at the county level. This county-to-county percentage matrix can be multiplied with the county-level production of resin to estimate the resin flow between counties. The results provide the county-level matrix of resin moving between resin manufacturers and plastic/rubber manufacturers.

5.9.5 Transportation

Truck Type

Plastic resin export shipments are typically shipped in 40-ft marine containers and the predominant package type in these container is 25-kg (55-lb) palletized bags. Other significant package types are 20-kg (44-lb) bags, octabins (around 500 kg or 1100 lbs), Super Sacks (around 1000 kg or 2200 lbs), or seabulk (personal communication, 2016). Figure 5.133 shows a five-axle truck carrying a 40-ft container.

Figure 5.133: Truck Transporting 40-ft container

Based on the information provided by industry experts, the domestic volume of plastic resin after packaging moves primarily in dry bulk tank trucks and some box van trucks. Figure 5.134 shows a typical dry bulk tank truck used for transporting plastic resins. Plastic resin can also be packaged in gaylord boxes, octobins, Super Sacks, or plastic bags on wooden pallets, and then transported by dry box van to manufacturing companies. Figure 5.135 shows a typical dry box van truck. According to Joel Morales, Director of Polyolefins Americas, IHS Chemical, the split between dry bulk tank trucks and dry box van trucks for transporting plastic resin is about 75% and 25%, respectively.

Figure 5.134: Dry Bulk Tank Truck Used for Transporting Plastic Resin

Figure 5.135: Typical Dry Box Van

Truck Capacity

The maximum weight capacity of a 40-ft standard container is 59,040 lbs. Due to the current overweight regulation in Texas, the capacity of the oceangoing containers is not fully used, even with an over-axle/over-gross weight tolerance permit. To comply with current weight regulations, containers carrying plastic resins are usually underloaded and transported to a transloading facility typically on port property. Additional product is added at the transloading facility to take full advantage of the capacity of the oceangoing containers.

The dry bulk tank trucks typically carry plastic resins weighing around 45,000 lbs and dry box van trucks carry about 42,000 lbs (Morales, 2016). These trucks usually only deliver product to customers and return empty. Some box vans may have a return move of cargo, but that is rare.

Converting Tonnage to Equivalent Trucks

Without knowing the exact amount of plastic resin flow moved within Texas, either from resin manufacturers to their customers within Texas or to the port for export, it is impossible to estimate the number of trucks on the Texas roadway system that are transporting plastic resin. However, major corridors near the Port of Houston that are used for moving plastic resins are identified.

5.9.6 Summary

The resin manufacturing industry and plastic and rubber manufacturing industry in total provided 48,676 employee positions in Texas. With more companies opening or expanding their facilities in Texas, the amount of resins, plastic, and rubber products moved on the Texas transportation network is expected to keep increasing in future years.

If information about how much plastic resin was consumed within Texas were to become available, the TWC and Texas Economic Development Corporation statistics regarding resin manufacturing and plastic and rubber manufacturing can be utilized to estimate the county-level production of plastic resin, and the flow of plastic resin from resin manufacturers to plastic and rubber manufacturers. However, without that information, a meaningful flow matrix cannot be developed and therefore no network analysis was performed.

Based on the research group’s study, it is expected that large amounts of plastic resin are shipped within the Houston and Dallas regions, with smaller inter-county flows from resin manufacturers to plastic and rubber manufacturers.

5.10 Sulfur and Sulfuric Acid

5.10.1 Background

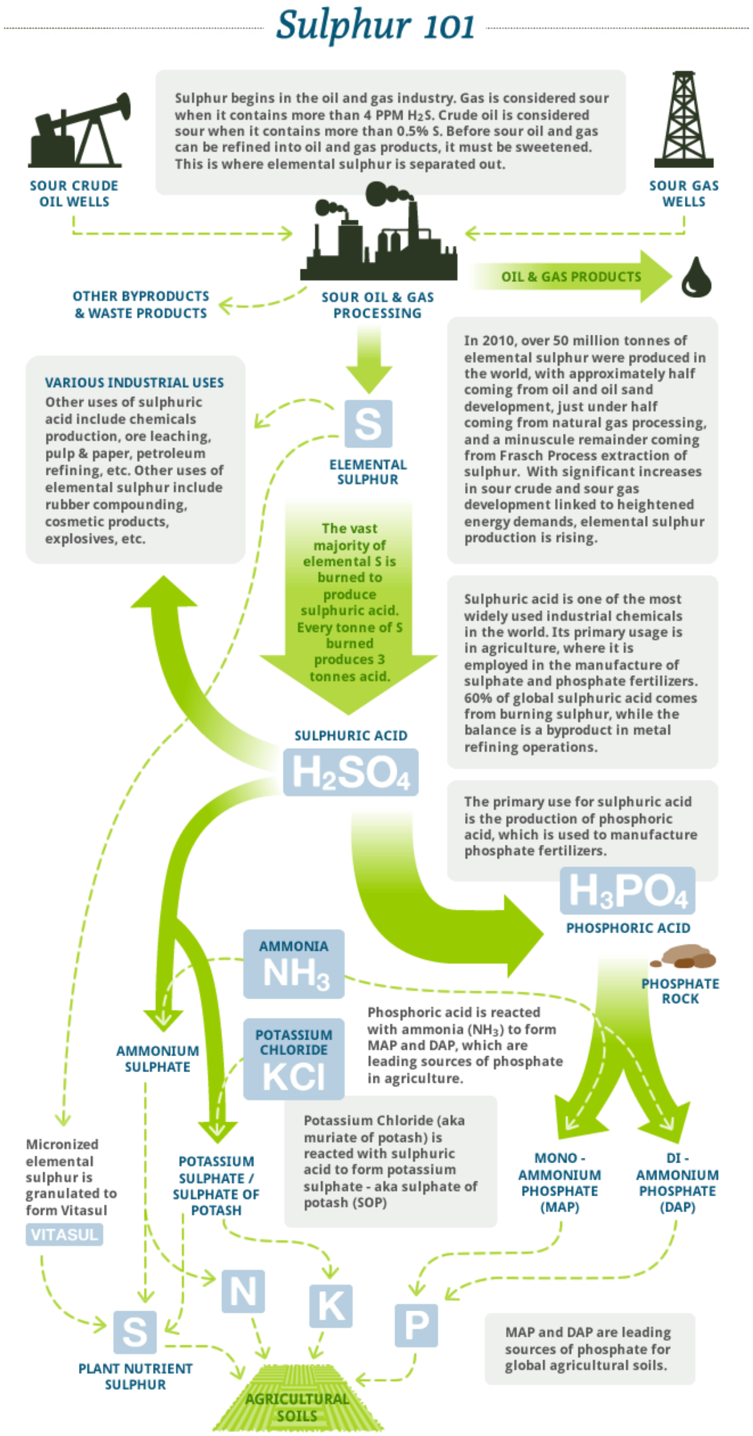
Worldwide, sulfur is generally used for fertilizers and agricultural chemicals. Almost all elemental sulfur is burned to produce sulfuric acid, of which more than half is used to produce phosphate and sulfate fertilizers (Sulvaris, Inc., 2012). In Texas, however, most sulfuric acid is used by the oil refineries along the Gulf Coast in the alkylation-spent sulfuric acid regeneration process.

Sulfuric acid ranks number one in the list of top ten US manufactured chemicals; in Texas, basic chemicals such as sulfuric acid make the state the leader in chemical production. Since it is one of the main chemicals produced both in Texas and in the US, sulfuric acid was chosen as the basic chemical recommended for commodity flow modeling.

Data from the US Census, Economic Indicators division, did not have export or import value limited to sulfur or sulfuric acid, providing just the value of basic chemicals exported from the Houston District in 2015—$20,103,449,696, which is the highest amount reported compared to the other monitored ports. The sour oil and gas refineries exist primarily in Houston and Corpus Christi.

5.10.2 Supply Chain

Figure 5.136 shows how the sulfur and sulfuric acid supply chain begins with the sour oil and gas processing facilities (refineries).



Sulphur begins in the oil and gas industry. Gas is considered sour when it contains more than 4 PPM H_2S. Crude oil is considered sour when it contains more than 0.5% S. Before sour oil and gas can be refined into oil and gas products, it must be sweetened. This is where elemental sulphur is separated out.

In 2010, over 50 million tonnes of elemental sulphur were produced in the world, with approximately half coming from oil and oil sand development, just under half coming from natural gas processing, and a minuscule remainder coming from Frasch Process extraction of sulphur. With significant increases in sour crude and sour gas development linked to heightened energy demands, elemental sulphur production is rising.

VARIOUS INDUSTRIAL USES
Other uses of sulphuric acid include chemicals production, ore leaching, pulp & paper, petroleum refining, etc. Other uses of elemental sulphur include rubber compounding, cosmetic products, explosives, etc.

The vast majority of elemental S is burned to produce sulphuric acid. Every tonne of S burned produces 3 tonnes acid.

Sulphuric acid is one of the most widely used industrial chemicals in the world. Its primary usage is in agriculture, where it is employed in the manufacture of sulphate and phosphate fertilizers. 60% of global sulphuric acid comes from burning sulphur, while the balance is a byproduct in metal refining operations.

The primary use for sulphuric acid is the production of phosphoric acid, which is used to manufacture phosphate fertilizers.

Phosphoric acid is reacted with ammonia (NH_3) to form MAP and DAP, which are leading sources of phosphate in agriculture.

Potassium Chloride (aka muriate of potash) is reacted with sulphuric acid to form potassium sulphate - aka sulphate of potash (SOP)

Micronized elemental sulphur is granulated to form Vitasul

MAP and DAP are leading sources of phosphate for global agricultural soils.

Figure 5.136: Sulfur Uses and Processing (Sulvaris, Inc., 2012)

Figure 5.137 shows the supply chains considered for this research, which begins with the sulfur captured at the sour oil and gas refineries. Texas used to have sulfur mines; however, when oil refineries began to capture sulfur, sulfur flooded the market and the sulfur mining facilities in Texas could no longer compete.

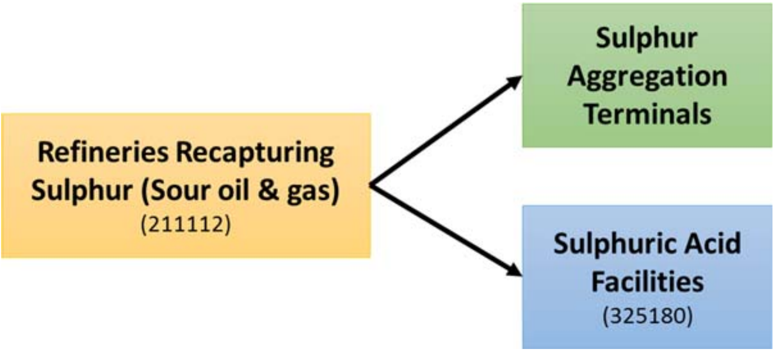


Figure 5.137: Sulfur and Sulfuric Acid Supply Chains

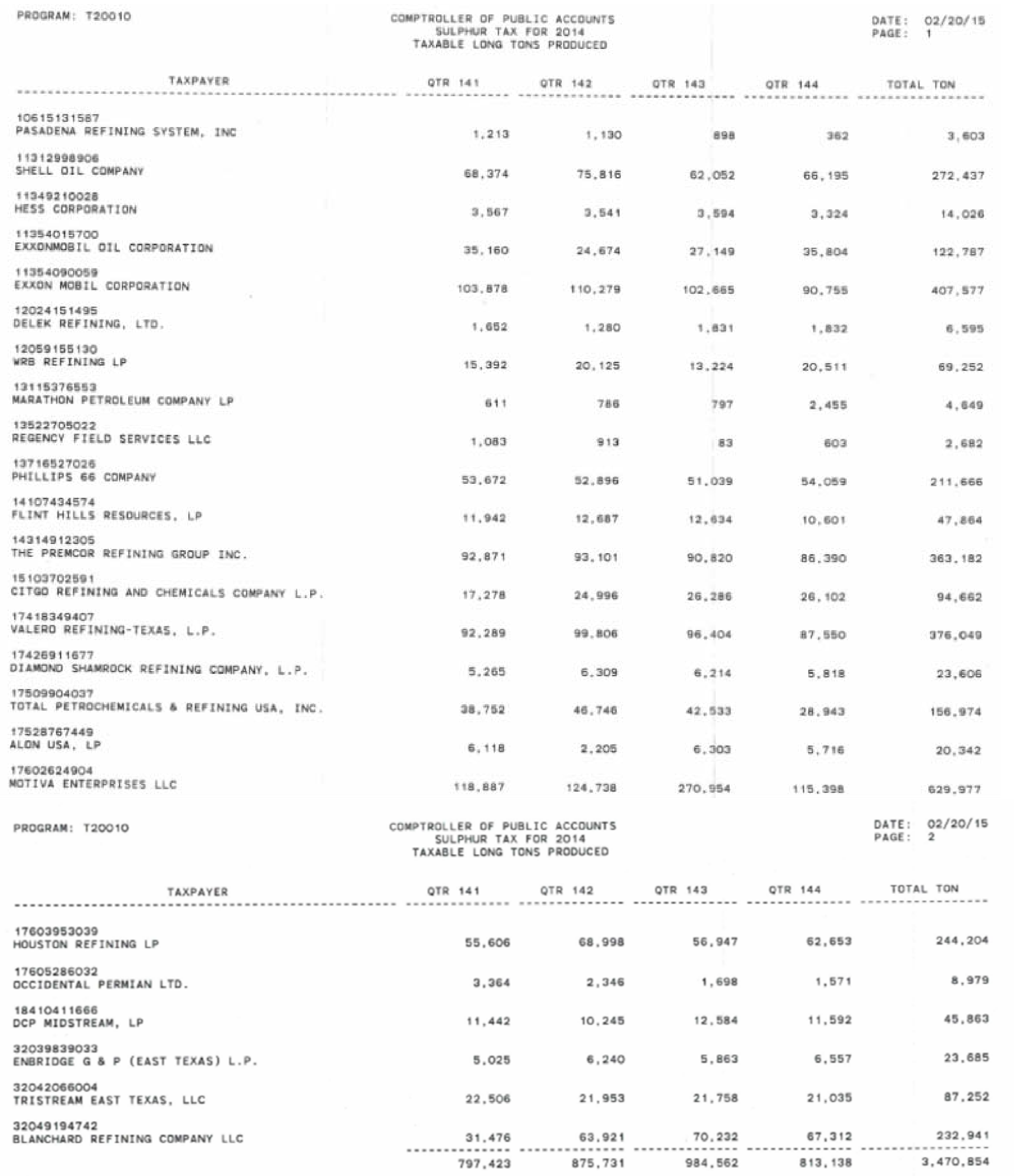
Sulfur captured at refineries is trucked either to terminals for export or to sulfuric acid manufacturing facilities and other local consumers of sulfur, usually within 20–30 miles of refineries, according to industry representative (Martin Resource, 2016).

In Texas, most manufacturing of sulfuric acid is for the oil refineries use in alkylation-spent sulfuric acid regeneration (Greener Industry, 2016). After the sulfuric acid is used as a catalyst, it is sent back to a sulfuric acid regeneration facility usually by pipeline (since facilities are usually in close vicinity) in a closed loop system that regenerates the sulfuric acid for use again as a catalyst. Sulfur can be added during the sulfuric acid regeneration to create excess sulfuric acid to sell on the market. Therefore, facilities that conduct sulfuric acid regeneration could potentially be sulfuric acid producers, which could be potentially trucked out.

5.10.3 Datasets

Sulfur Sources

Until August 2015, the State of Texas levied taxes on the capture of sulfur from refineries. The Texas Comptroller of Public Accounts reported the payers of that tax, their location, and quarterly and annual taxable long tons of sulfur produced (Figure 5.138). That report (for year 2014, most recent) provides the company name and supply of sulfur produced in Texas, but not the specific location the sulfur is captured.



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PROGRAM: T20010                          COMPTROLLER OF PUBLIC ACCOUNTS                                DATE:  02/20/15
                                               SULPHUR TAX FOR 2014                                    PAGE:  1
                                           TAXABLE LONG TONS PRODUCED

                   TAXPAYER                           QTR 141       QTR 142       QTR 143       QTR 144        TOTAL TON
------------------------------------------------ ------------- ------------- ------------- ------------- ----------------

10615131587
PASADENA REFINING SYSTEM, INC                           1,213         1,130           898           362            3,603

11312998906
SHELL OIL COMPANY                                      68,374        75,816        62,052        66,195          272,437

11349210028
HESS CORPORATION                                        3,567         3,541         3,594         3,324           14,026

11354015700
EXXONMOBIL OIL CORPORATION                             35,160        24,674        27,149        35,804          122,787

11354090059
EXXON MOBIL CORPORATION                               103,878       110,279       102,665        90,755          407,577

12024151495
DELEK REFINING, LTD.                                    1,652         1,280         1,831         1,832            6,595

12059155130
WRB REFINING LP                                        15,392        20,125        13,224        20,511           69,252

13115376553
MARATHON PETROLEUM COMPANY LP                             611           786           797         2,455            4,649

13522705022
REGENCY FIELD SERVICES LLC                              1,083           913            83           603            2,682

13716527026
PHILLIPS 66 COMPANY                                    53,672        52,896        51,039        54,059          211,666

14107434574
FLINT HILLS RESOURCES, LP                              11,942        12,687        12,634        10,601           47,864

14314912305
THE PREMCOR REFINING GROUP INC.                        92,871        93,101        90,820        86,390          363,182

15103702591
CITGO REFINING AND CHEMICALS COMPANY L.P.              17,278        24,996        26,286        26,102           94,662

17418349407
VALERO REFINING-TEXAS, L.P.                            92,289        99,806        96,404        87,550          376,049

17426911677
DIAMOND SHAMROCK REFINING COMPANY, L.P.                 5,265         6,309         6,214         5,818           23,606

17509904037
TOTAL PETROCHEMICALS & REFINING USA, INC.              38,752        46,746        42,533        28,943          156,974

17528767449
ALON USA, LP                                            6,118         2,205         6,303         5,716           20,342

17602624904
MOTIVA ENTERPRISES LLC                                118,887       124,738       270,954       115,398          629,977

PROGRAM: T20010                          COMPTROLLER OF PUBLIC ACCOUNTS                                DATE:  02/20/15
                                               SULPHUR TAX FOR 2014                                    PAGE:  2
                                           TAXABLE LONG TONS PRODUCED

                   TAXPAYER                           QTR 141       QTR 142       QTR 143       QTR 144        TOTAL TON
------------------------------------------------ ------------- ------------- ------------- ------------- ----------------

17603953039
HOUSTON REFINING LP                                    55,606        68,998        56,947        62,653          244,204

17605286032
OCCIDENTAL PERMIAN LTD.                                 3,364         2,346         1,698         1,571            8,979

18410411666
DCP MIDSTREAM, LP                                      11,442        10,245        12,584        11,592           45,863

32039839033
ENBRIDGE G & P (EAST TEXAS) L.P.                        5,025         6,240         5,863         6,557           23,685

32042066004
TRISTREAM EAST TEXAS, LLC                              22,506        21,953        21,758        21,035           87,252

32049194742
BLANCHARD REFINING COMPANY LLC                         31,476        63,921        70,232        67,312          232,941
                                                 ------------- ------------- ------------- ------------- ----------------
                                                      797,423       875,731       984,562       813,138        3,470,854
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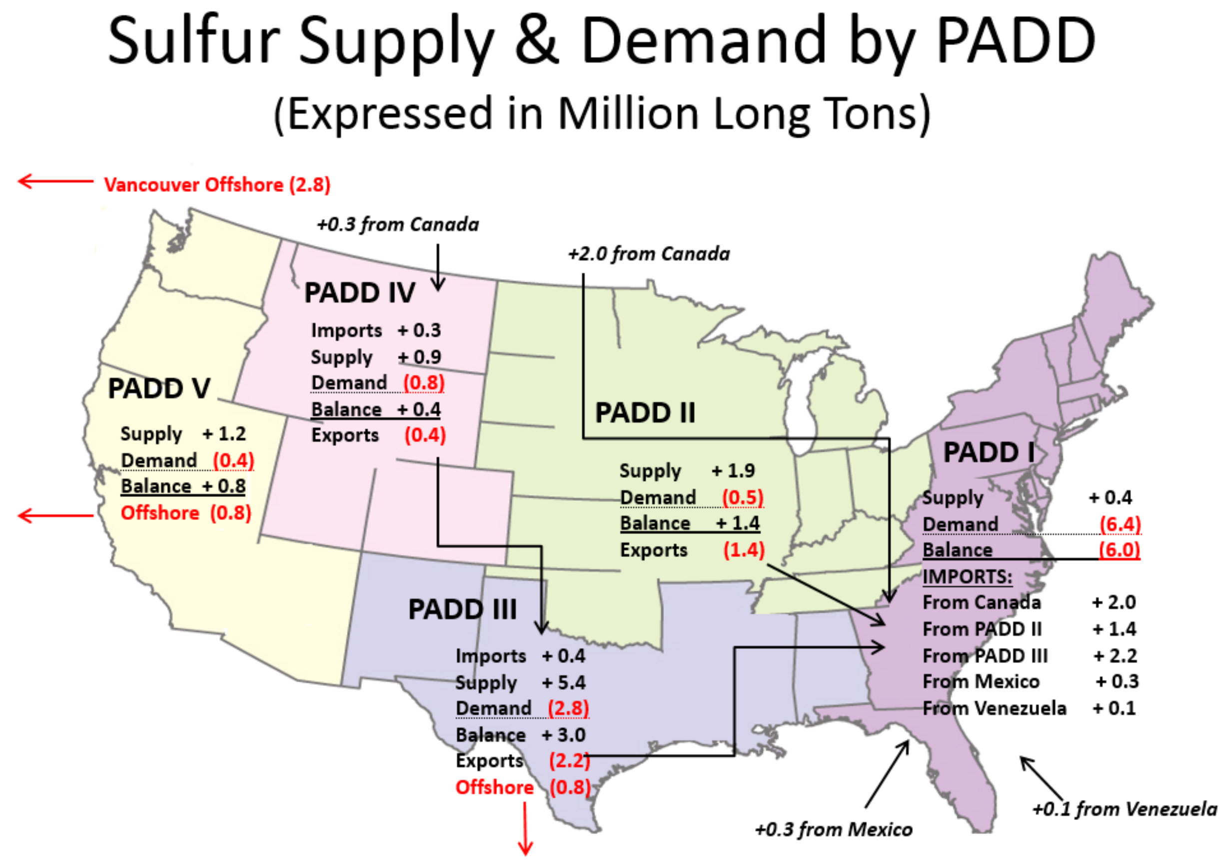
Figure 5.138: Sulfur Tax Report 2014 from Texas Comptroller of Public Accounts

Interestingly, the 2013 TWC data still showed 17 facilities with a NAICS code that includes sulfur mining, but all of those facilities mine substances such as phosphate, barium sulfate, and calcium carbonate, and not sulfur.

Texas is a net exporter of sulfur (Figure 5.139), and most of the sulfur imported into Texas (0.4 million long tons) is going through Texas on rail to the ports for export (rather than for consumption within the state) and most sulfur being exported out of the state (2.2 million long tons) is going to Tampa, Florida to a phosphatic fertilizer plant.



Source: U.S. Energy Information Administration (2011)

Figure 5.139: Sulfur Flow for Texas

Sulfur and Sulfuric Acid Consumers

For this research, the focus is on the supply chain from sulfur to terminals and to sulfuric acid manufacturing facilities, although consideration was given to fertilizer plants until closer examination of the data. There are other consumers of the sulfur captured at the refineries; however, due to the lack of data sources for the location and demand of those facilities (other than an estimation provided by Martin Resource Management of some of the customers), the decision was made to focus on the terminals and sulfuric acid manufacturing facilities. In practical terms, since the sulfur customers are generally within 20 to 30 miles of the refineries, the OD estimation of those flows will not be captured within the OD county flow matrix. That appears to be the case for the sulfur supply chain in Texas.

Two data sources provided information on fertilizer plants in Texas: a map from The Fertilizer Institute (TFI) and the 2013 TWC data. The TFI map showed only one phosphatic fertilizer plant, located in Pasadena, Texas. The 2013 TWC data shows three phosphatic fertilizer manufacturing facilities (NAICS code 325312) in Texas; however, after further research, it was determined none of those produce phosphatic fertilizers. The Pasadena plant (the same as the one shown by TFI) used to produce phosphatic fertilizer but was discontinued and that facility produces sulfuric acid and ammonium sulfate instead. Another focuses on water treatment chemicals. And the other listed facility is for producing liquid fertilizer. In discussions with a major logistics company for sulfur, the sulfur captured in Texas for phosphatic fertilizer manufacturing is exported to either Tampa, Florida, where Mosaic is located (the largest producer of phosphatic fertilizers in United States because of large phosphate rock deposits in the area), or to facilities in other countries. Sulfur is what is shipped and then the sulfuric acid needed as input into phosphatic fertilizer manufacturing is done in or near the fertilizer facility.

Sulfur captured at sour oil and gas refineries in Texas is trucked as molten sulfur and then either remains as molten sulfur (to be barged to the Tampa, Florida port's phosphatic fertilizer plant), or becomes aggregated dried granules, which are stored in storage yards, then shipped out in dry bulk vessels to ports around the world, with most of that sulfur being used to produce sulfuric acid. There are four sulfur aggregation facilities/terminals in Texas:

- Martin Resource Management in Beaumont
- Gulf/Salvage Sulfur Services (a joint venture between Savage and Mosaic) in Galveston
- Koch in Corpus Christi
- Mosaic in Channelview (Houston area)

For the sulfuric acid manufacturing facilities, two data sources were found and reviewed: the 2013 TWC data and the "Sulfuric Acid on the Web" acid plant database. According to the 2013 TWC data, Texas has 81 manufacturers, whereas the "Sulfuric Acid on the Web" acid plant database lists 10 manufacturers (Sulphuric Acid on the Web, 2010). The higher number of manufacturers listed in the TWC data is due to the NAICS code of 325180 including more than just sulfuric acid manufacturing facilities (the NAICS title for that code is "Other Basic Inorganic Chemical Manufacturing"). Table 5.27 (Sulfuric Acid on the Web, 2010) shows that only two of the plants from the acid plant database generate sulfuric acid; the rest use sulfuric acid as part of the acid regeneration process.

Table 5.27: Sulfuric acid manufacturing

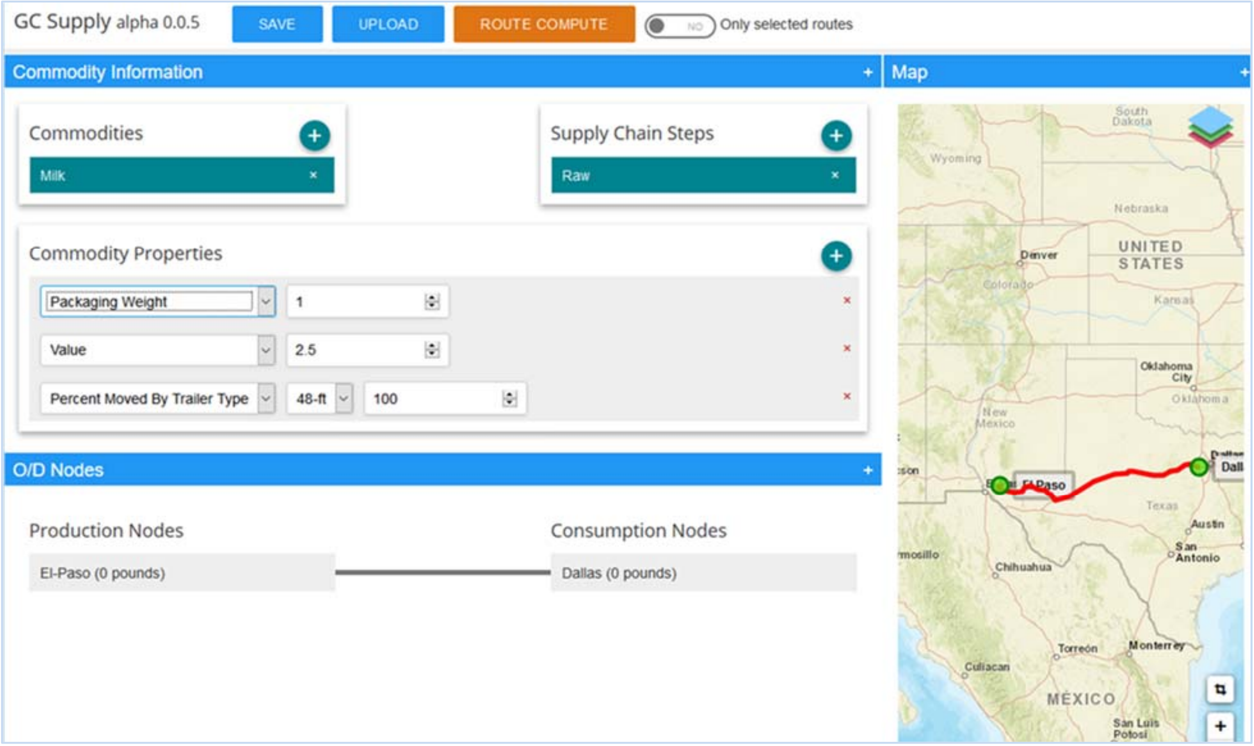
Company Name	City in Texas	Type of Sulfuric Acid Plant	Metric tons per day (MTPD)
Rentech Nitrogen Partners	Pasadena	Sulfur burner (elemental sulfur)	1650
Chemtrade	Beaumont	Acid regeneration (alkylation spent acid)	825
Chemours Company	El Paso	Acid regeneration (alkylation spent acid, hydrogen sulfide gas)	n/a
Chemours Company	LaPorte	Acid regeneration (alkylation spent acid, elemental sulfur)	940
Lucite	Nederland	Acid regeneration (spent acid from MM process)	625
Martin Midstream	Plainview	Sulfur burner (elemental sulfur)	500 STPD
Rhodia	Baytown	Acid regeneration (alkylation spent acid)	800
Rhodia	Houston	Acid regeneration (alkylation spent acid)	1250 STPD and 1690 STPD
Rohm and Haas	Deer Park	Acid regeneration	n/a
Valero	McKee Refinery	Acid regeneration (alkylation spent acid)	100 STPD

5.10.4 Commodity Flow Estimation

The first link of sulfur supply chain begins with the facilities that capture sulfur for truck transport to either local consumers of the sulfur (e.g., sulfuric acid plants and oil refineries for acid regeneration) or the terminals for export, which generally happens within 20–30 miles, within the same county. Therefore, a county-to-county flow matrix was not developed. Instead, a facility-to-facility flow estimation was conducted using a toolkit developed in this project.

Commodity Flow Visualization Toolkit

To enable end-to-end simulation of a commodity's supply chain and on-the-fly visualization of how changes to the various steps of the supply chain influence overall truck trips on the Texas network, the research team developed a JavaScript-based toolkit to analyze commodities. The toolkit determines where a commodity will be shipped and its total value along particular corridors based on a few simple inputs. Figure 5.140 shows the toolkit input screen.



Commodities: Milk

Supply Chain Steps: Raw

Packaging Weight: 1

Value: 2.5

Percent Moved By Trailer Type: 48-ft 100

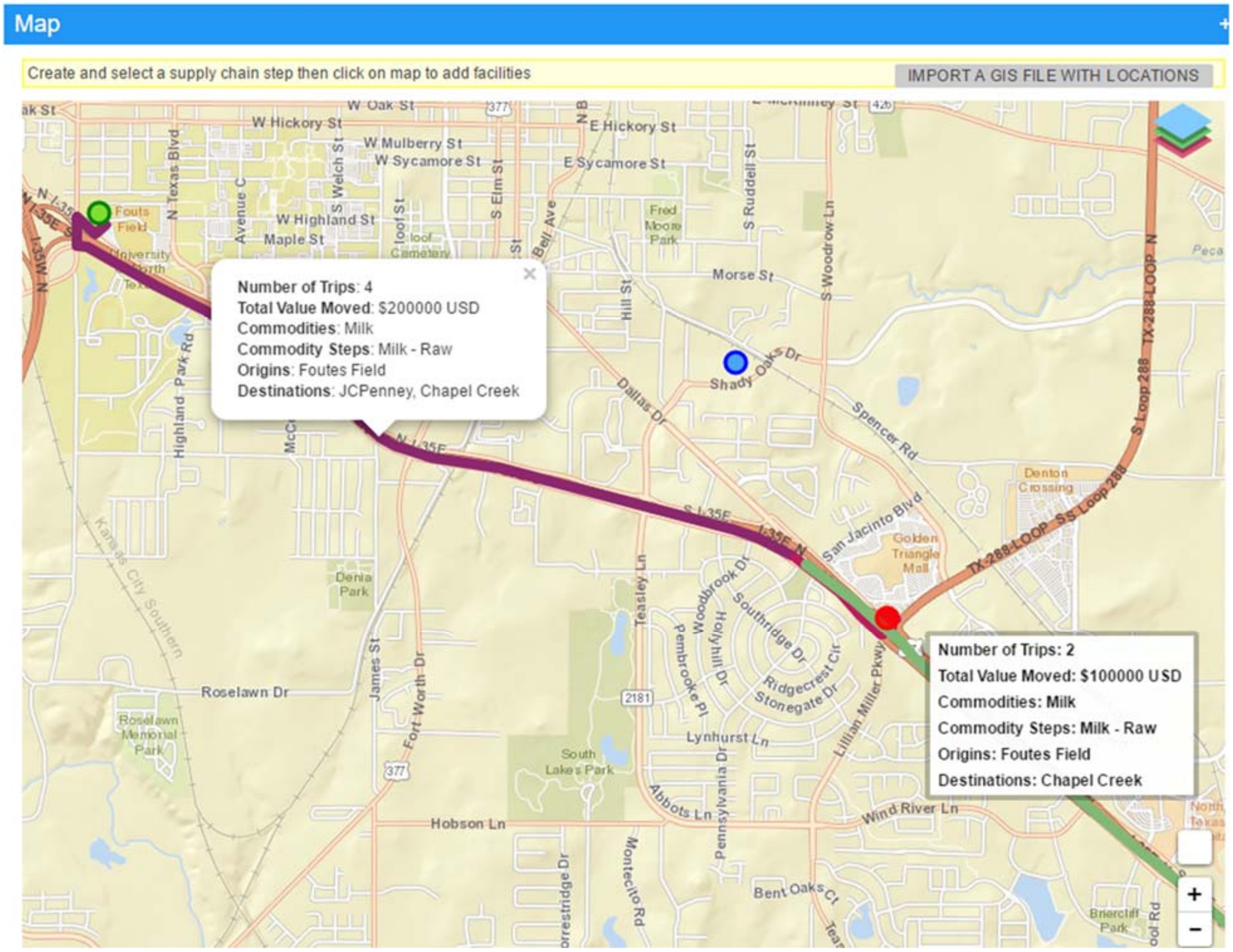
Production Nodes: El-Paso (0 pounds)

Consumption Nodes: Dallas (0 pounds)

Figure 5.140: Toolkit Input Screen for Raw Milk

The toolkit takes information about a commodity's size and weight to determine whether the commodity will weigh-out (reach the truck's permitted weight limit before reaching volumetric capacity) or cube-out (reach the truck's volumetric capacity before reaching the permitted weight limit) for shipping. Then, based on input production nodes and attraction nodes, the toolkit will determine the total number of truck trips required for the commodity and assign the truck trips to the Google Maps transportation network. With input about the value of each unit of the commodity, the toolkit is able to determine the value being transported.

The ultimate goal of developing this toolkit is to use it to help distribute the trucks on the road network instead of performing traffic assignment using TransCAD. However, the researchers' input regarding location of origins, destinations, and amount shipped between origins and destinations are still required. Figure 5.141 provides example output.



Number of Trips: 4
Total Value Moved: $200000 USD
Commodities: Milk
Commodity Steps: Milk - Raw
Origins: Foutes Field
Destinations: JCPenney, Chapel Creek

Number of Trips: 2
Total Value Moved: $100000 USD
Commodities: Milk
Commodity Steps: Milk - Raw
Origins: Foutes Field
Destinations: Chapel Creek

Figure 5.141: Example Output from the Toolkit

Sulfur Trip Generators and Destinations

As explained earlier, the study of sulfur movement focus on the supply chain from sulfur producer to terminals and to sulfuric acid manufacturing facilities. Sulfur trip generators and destinations can be identified based on information of sulfur producers in Texas provided in the Texas comptroller tax report (Figure 5.138), the four sulfur aggregation facilities/terminals in Texas and sulfuric acid manufacturing facilities in Texas (Table 5.27). These facilities are depicted in Figure 5.142. The three circled areas (Corpus Christi, Houston and Texas City, Beaumont and Port Arthur) will be selected for more detailed analysis in the following sections.

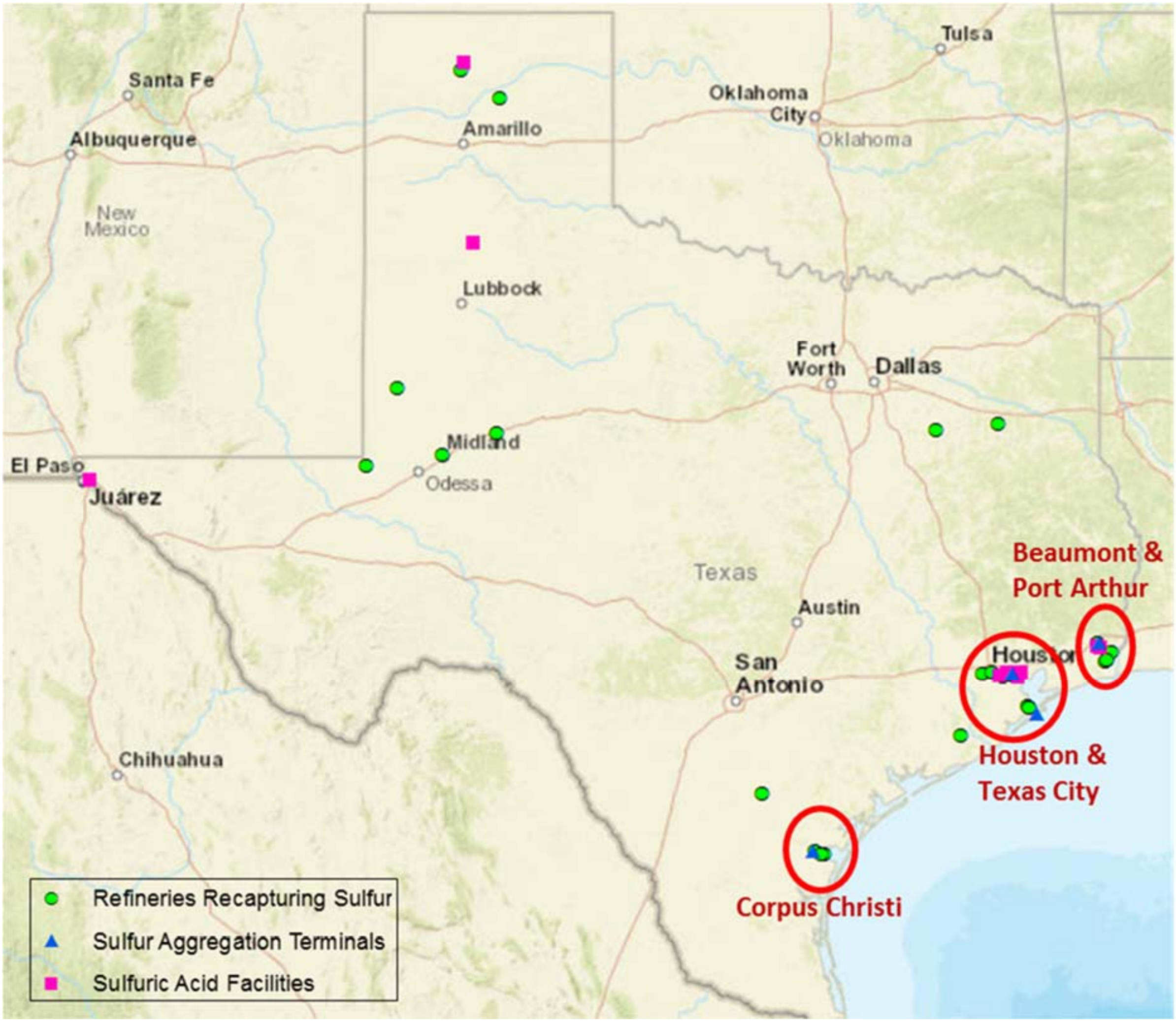


Figure 5.142: Sulfur Trip Generators and Destinations

Trip Distribution

As noted earlier, sulfur is usually shipped from the producer to nearby consumers within 20 to 30 miles. For example, the sulfur produced at refineries located in Texas City is shipped to the Savage Sulfur Service located in Galveston. The number of sulfur truck trips generated from those origins can be estimated based on the production of sulfur reported in the Texas comptroller tax report. However, no data was found to support the estimation of consumption at those destinations. The distribution of trips between an origin and all of its destinations is assumed to be equal. This can be easily modified if new information or data becomes available later. The number of trips moved from origins to destinations in the three case study areas will be assigned to the road network in the network analysis section.

5.10.5 Transportation

Sulfur is transported both as a solid, in bulk, and as a liquid, in molten form. Each form has special requirements for safe transport, with minimal environmental impact and minimal contamination of the sulfur.

The key to transporting sulfur in molten form is maintaining its temperature at approximately 140ºC. Transport over short distances can be done in well-insulated containers. The low thermal conductivity of sulfur minimizes heat loss and helps it to retain heat so it does not solidify. Over longer distances, a heating system is required to maintain the sulfur in the liquid state.

A typical semi-trailer for transporting molten sulfur is shown in Figure 5.143. The capacity of the tank is approximately 3,800 US gallons; the tank is constructed of stainless steel and insulated.

Tank trailers designed for molten sulfur are generally dedicated to hauling molten sulfur. A tank that has just carried molten sulfur cannot be easily cleaned so that the trailer can carry a different commodity on the return trip or to another destination. The result is that the tank is full on the delivery trip but is empty on the return trip.

Figure 5.143: Standard Molten Sulfur Trailer

The density of liquid sulfur is 1.819 g/cm3. A 3,800-gallon tank truck can carry 28.8425 US tons of sulfur. Based on reported 2014 price of elemental sulfur, each US ton of sulfur is worth $95 (Mineral Commodity Summaries, 2015). Thus, the value of sulfur carried by a 3,800-gallon tank truck is approximately $2,740.

5.10.6 Network Analysis

The network analysis for the three case study areas will be performed using the web-based application tool described earlier. The truck volumes are estimated based on 2014 sulfur production shown in Figure 5.138 and tank truck size discussed in last section.

Figures 5.144 through 5.147 demonstrate the simulated route choice of sulfur transportation in several gulf coast areas. The green dots in those figures are origins and red dots are destinations of sulfur movement in each area. The routes between different OD pairs are shown by different colors. By drawing a query box on any part of the road used by sulfur trucks on the map, the number of trucks and value moved by that section of roadway will be displayed on the map.

Corpus Christi

Figure 5.144 indicates that the routes that most likely used by trucks carrying sulfur in Corpus Christi is IH 37, which is a part of the primary freight network. The most heavily used section of IH 37 by sulfur transportation carries 9,872 sulfur tank trucks, totaling approximately $27 million. Table 5.28 summarizes some statistics pertaining to the sulfur truck trips in this area.

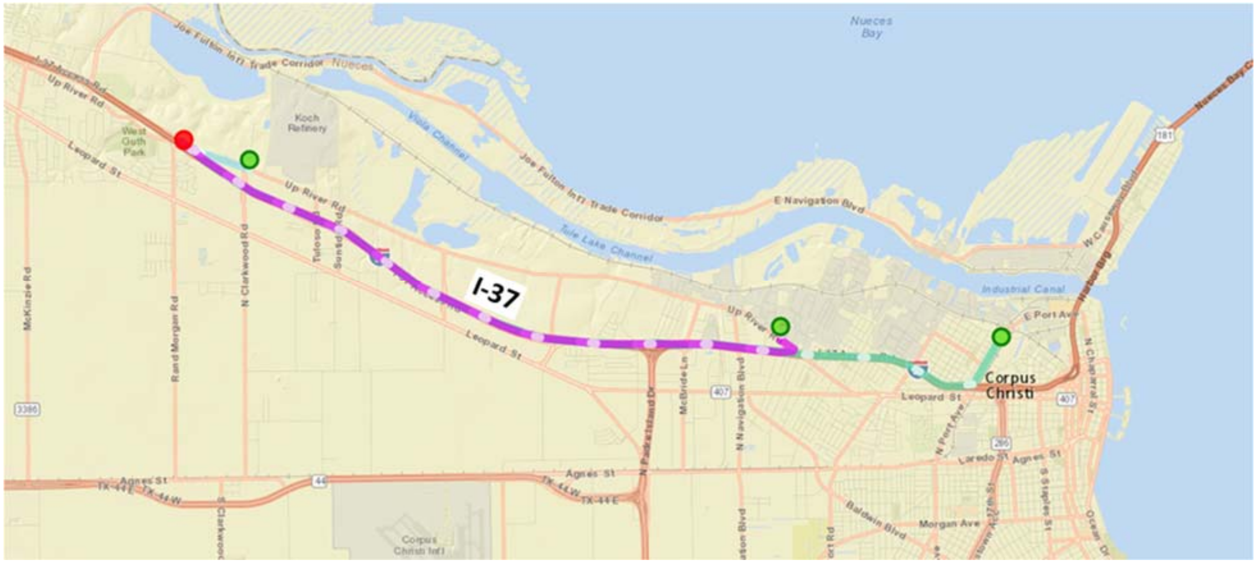


Figure 5.144: Sulfur Trip Routes in Corpus Christi

Table 5.28: Statistics of sulfur truck trips in Corpus Christi area

Origins	Flint Hills, Valero at Corpus Christi, Citgo
Destinations	Koch
Total Number of Truck Trips	11,731
Total Value Moved (USD)	$32,140,674

Houston

Figure 5.145 shows the road sections that are most likely used by trucks carrying sulfur in the Houston area. With the exception of Federal Road and SH 8, all other road sections used by sulfur trucks in this area are on the primary or secondary freight network. Table 5.29 summarizes some statistics pertaining to the sulfur truck trips in this area.

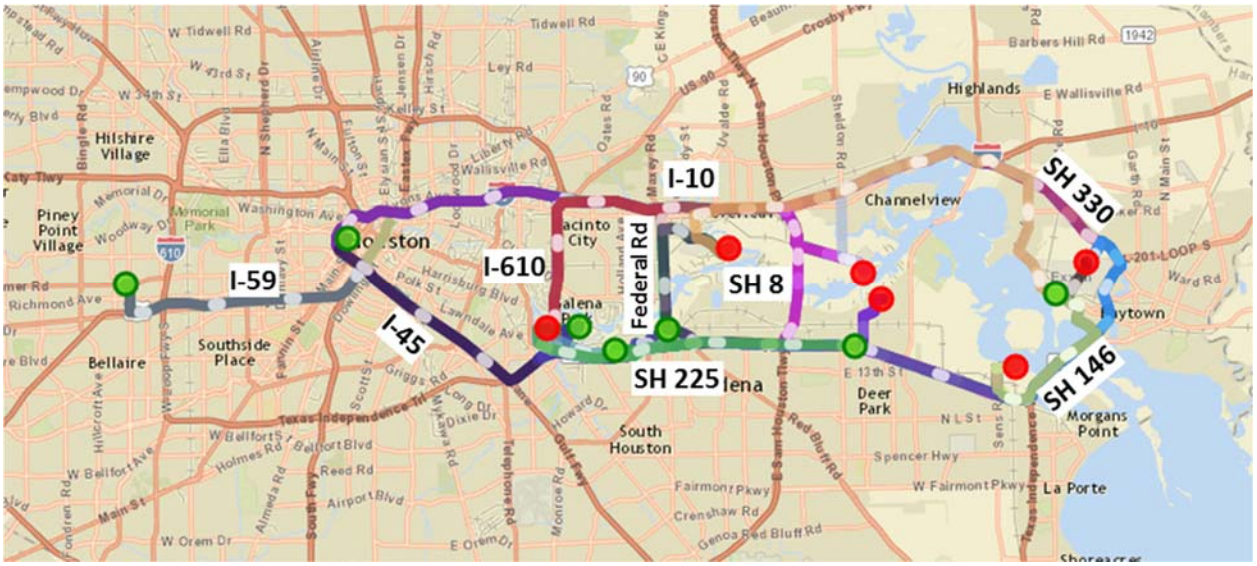


Figure 5.145: Sulfur Trip Routes in Houston

Table 5.29: Statistics of sulfur truck trips in Houston area

Origins	DCP, Enbridge, Valero at Houston, Houston Refining LP, Pasadena Refining System, Shell at Deer Park, ExxonMobil at Baytown
Destinations	Mosaic, Agrifos Fertilizers Inc., Rhodia Inc., Rohm and Haas Texas, Inc., The Chemours Company
Total Number of Truck Trips	34,776
Total Value Moved (USD)	$95,241,938

Texas City

Figure 5.146 identifies the route most likely to be used by trucks carrying sulfur in Texas City as IH 45, which is part of the primary freight network. It carries 15,435 sulfur tank trucks annually, worth approximately $42.3 million. Table 5.30 summarizes some statistics pertaining to the sulfur truck trips in this area.

Figure 5.146: Sulfur Trip Routes in Texas City

Table 5.30: Statistics of sulfur truck trips in Texas City area

Origins	Marathon, Valero at Texas City
Destinations	Savage Sulfur Services
Total Number of Truck Trips	15,435
Total Value Moved (USD)	$42,287,084

Beaumont and Port Arthur

Figure 5.147 identifies the routes most likely to be used by trucks carrying sulfur in Beaumont and Port Arthur as FM 366 and US 96/US 69/US 287. FM 366 is part of the secondary freight network and US 96 is part of the primary freight network. FM 366 carries 6,096 sulfur tank trucks annually, which is worth approximately $16.7 million. US 96 carries 19,428 sulfur tank trucks annually, which is worth approximately $53.2 million. Table 5.31 summarizes some statistics pertaining to the sulfur truck trips in this area.

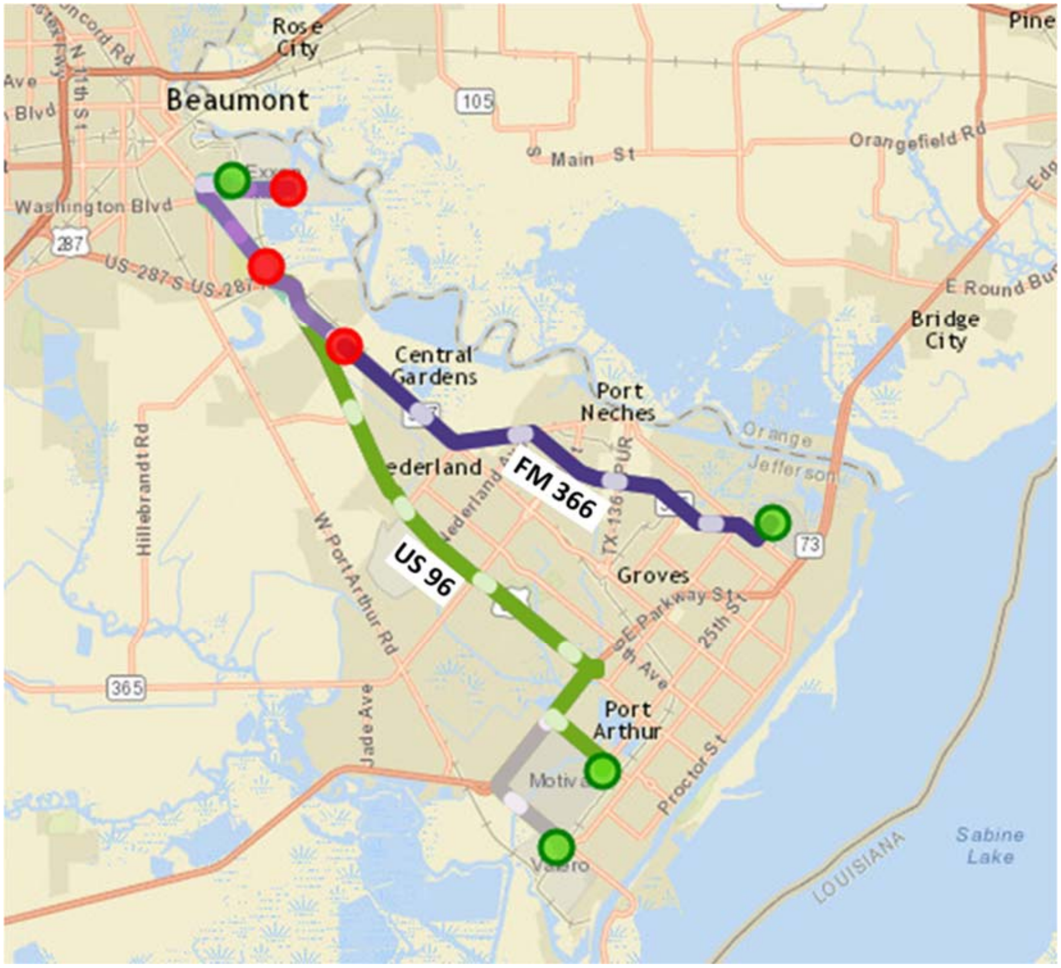


Figure 5.147: Sulfur Trip Routes in Beaumont and Port Arthur

Table 5.31: Statistics of sulfur truck trips in Beaumont and Port Arthur area

Origins	ExxonMobil at Beaumont, Valero at Port Arthur, Shell at Port Arthur, Total
Destinations	Martin Resource Management, Chemtrade, Lucite International, Inc.
Total Number of Truck Trips	30,294
Total Value Moved (USD)	$82,986,467

5.10.7 Summary

Sulfuric acid ranks number one in the list of top ten US manufactured chemicals; in Texas, basic chemicals such as sulfuric acid make the state the leader in chemical production. Most sulfuric acid in Texas is used by the oil refineries along the Gulf Coast in the alkylation-spent sulfuric acid regeneration process.

The Texas comptroller tax report identifies sulfur aggregation facilities/terminals and sulfuric acid manufacturing facilities in Texas; this information was used to identify the origination and destination of sulfur trips. However, because sulfur is usually transported within 20–30 miles to either local consumers or a nearby terminal for export, a county-to-county flow matrix was not developed. Instead, the local movements of sulfur were modeled using the web-based toolkit developed by the research team. This toolkit takes input information regarding the location of origins and destinations and the amount of commodities moved between each OD pair and assigns the flow to the Google network. This toolkit allows for detailed analysis in a specific area without limiting trucks to the freight network.

The analysis results showed that most sulphur trips in those Gulf Coast areas are still using the primary or secondary freight corridors, indicating the importance of those corridors to not only the state but also the local economy.

Chapter 6. Compare Analysis Results with TDMS Data

As mentioned in the beginning of Section 4.4, the research team also compared the link-level truck volume obtained from network analysis with TDMS data. However, as mentioned earlier, TDMS data was only collected at 1269 traffic stations, which covers only a small portion of all the links on the network used in this study. To make the comparison on all the links included in the network, the research team developed a methodology to estimate the volume and the distribution of vehicle types for Texas roadways based on daily, monthly, and annual vehicle class distribution data from the TDMS. The estimation include two steps:

1) assigning station-based traffic volume data from TDMS to links in the freight network. To achieve this, a method for matching TDMS station with the road network links was developed.
2) developing a method to estimate the volumes of different types of vehicles on links without direct TDMS measurements.

6.1 TDMS Data Processing

6.1.1 Summary of Steps

The process of estimating and visualizing the distribution of vehicle types consisted of six major steps (Figure 6.1):

- TDMS data acquisition
- Creating Texas freight network (see Section 4.3.1 for more details)
- TDMS data screening
- TDMS data matching
- Link traffic volume estimation
- Visualization of distribution

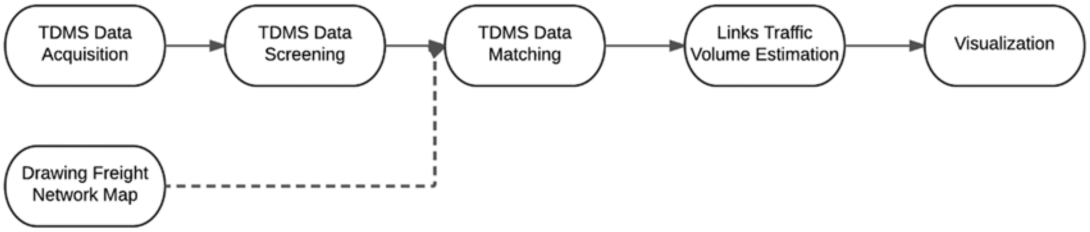
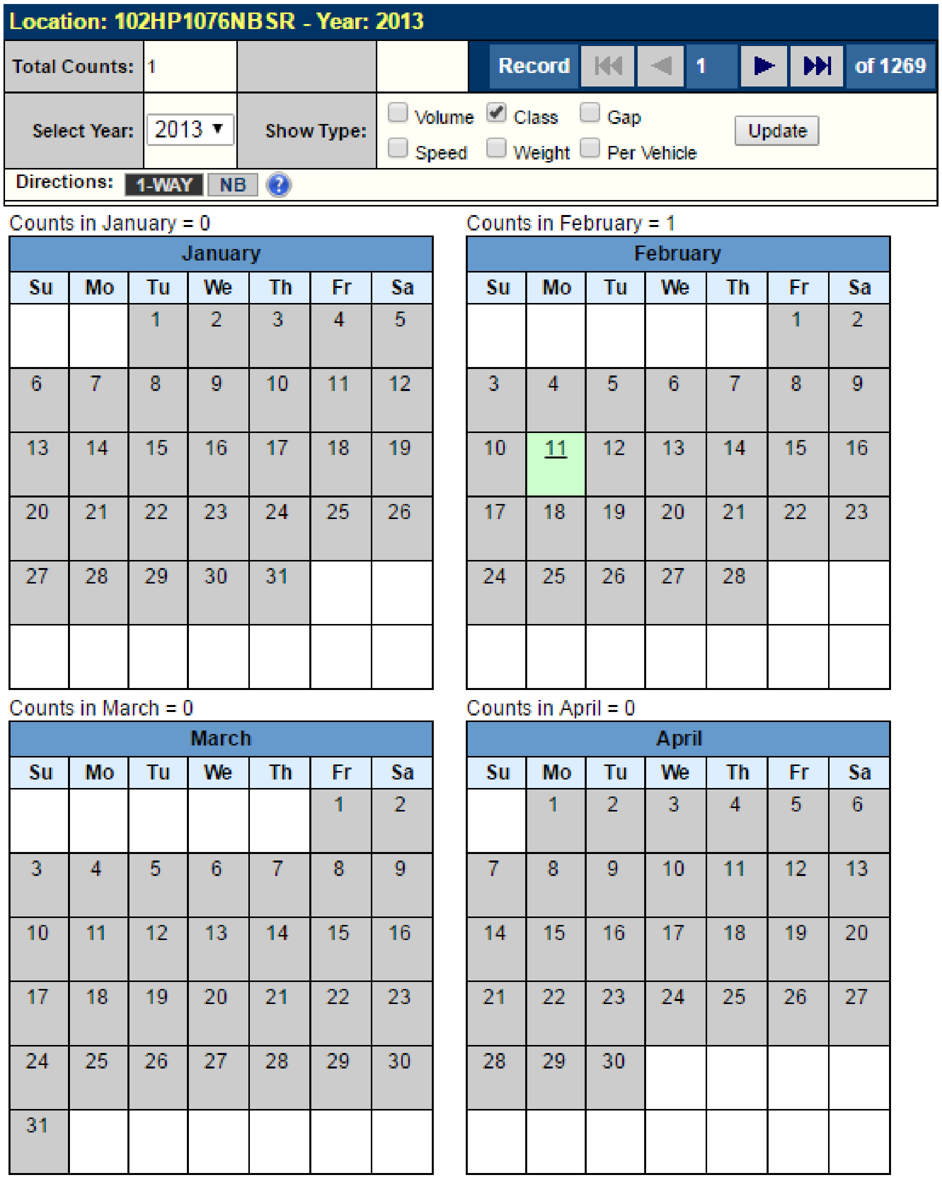


Figure 6.1: Vehicle Distribution Estimation Process Flowchart

The research team first acquired the TDMS data by using a customized data-crawling technique (a technique to automatically retrieve and acquire large amount of data from a webpage quickly). Then, useful information and traffic volume data were retrieved from TDMS. The distribution of vehicle types is visualized through the ArcMap platform using the screened raw data. Next, TDMS stations were matched with the links on the freight network map and traffic volumes are assigned to their matched links. However, many links don’t have traffic volume data assigned due to lack of TDMS station on these links. Traffic volume on these links were estimated through an algorithm. Finally, the distributions of total traffic and truck volume are visualized through the ArcMap platform.

6.1.2 TDMS Data Acquisition

The team developed a data-crawling program to automatically retrieve data from the TDMS database. One challenge was that the availability of data varies from station to station over time. The latest year of observation is 2014. Most stations have no more than one traffic count measurement in each year, and the dates of measurement are mostly different. Figure 6.2 shows a snapshot of data availability for one of the stations, which illustrates that a measurement is only available from February 11, 2013.



Location: 102HP1076NBSR - Year: 2013

Total Counts: 1

Select Year: 2013 ▼

Show Type: ☐ Volume ☑ Class ☐ Gap ☐ Speed ☐ Weight ☐ Per Vehicle

Directions: 1-WAY NB

Counts in January = 0

Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

Counts in February = 1

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28		

Counts in March = 0

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Counts in April = 0

Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

Figure 6.2: Traffic Counts Availability Example

The uneven distribution of data from TDMS called for a balance in the spatial coverage and temporal consistency. To address this challenge, the research team used data-crawling technique to scan measurements of each station in 2013 and 2014. Two data files were obtained for each station, namely:

- Vehicle type distribution: daily traffic volume of each vehicle type.
- Vehicle volume: hourly volume of all vehicle types.

6.1.3 TDMS Data Summary Statistics

The data acquired from the TDMS were taken from different observation stations—a total of 1269 traffic stations with vehicle class measurements. The locations of traffic stations are shown in Figure 6.3. Among these traffic stations, 865 reported vehicle-type data at least once in 2013 and 2014. Figure 6.4 shows February 11, 2013, measurements for station 102HP1076NBSR.

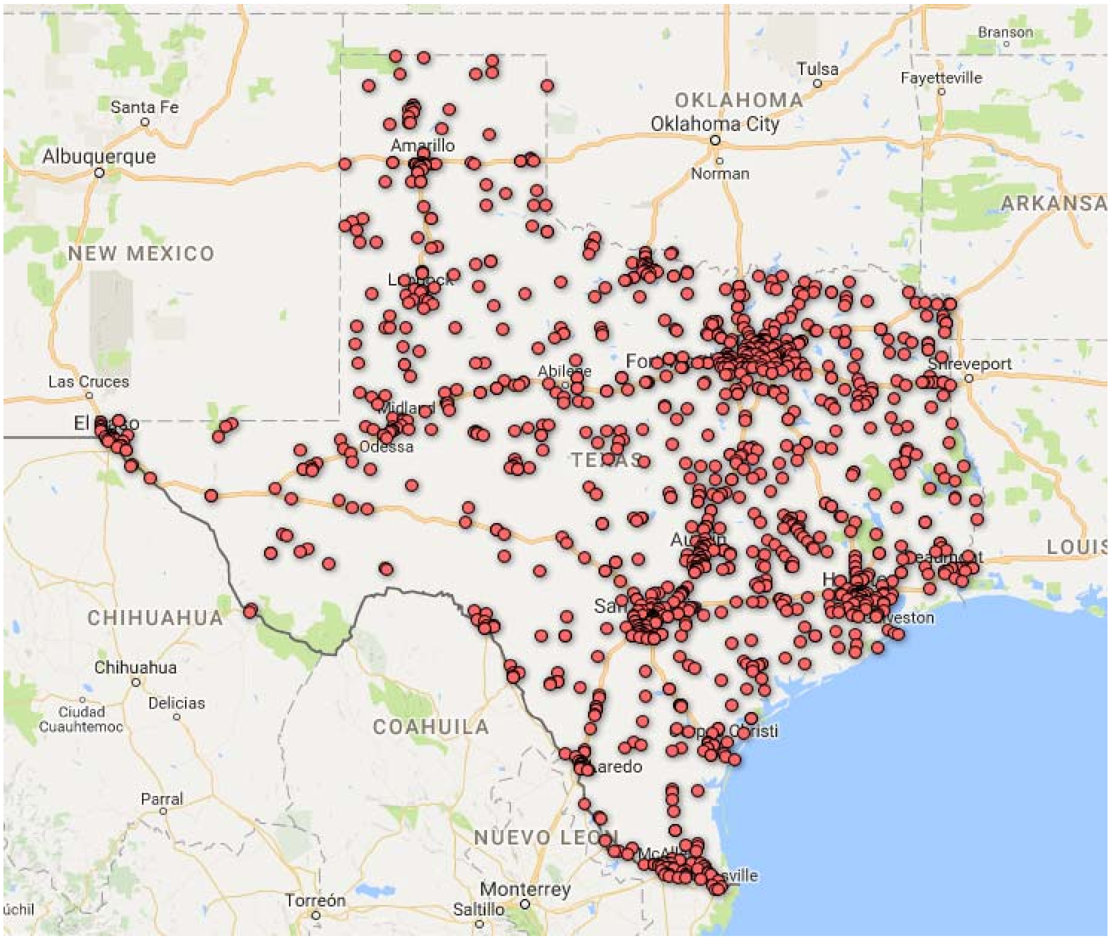


Figure 6.3: Locations of 1269 Traffic Stations with Vehicle Class Measurements

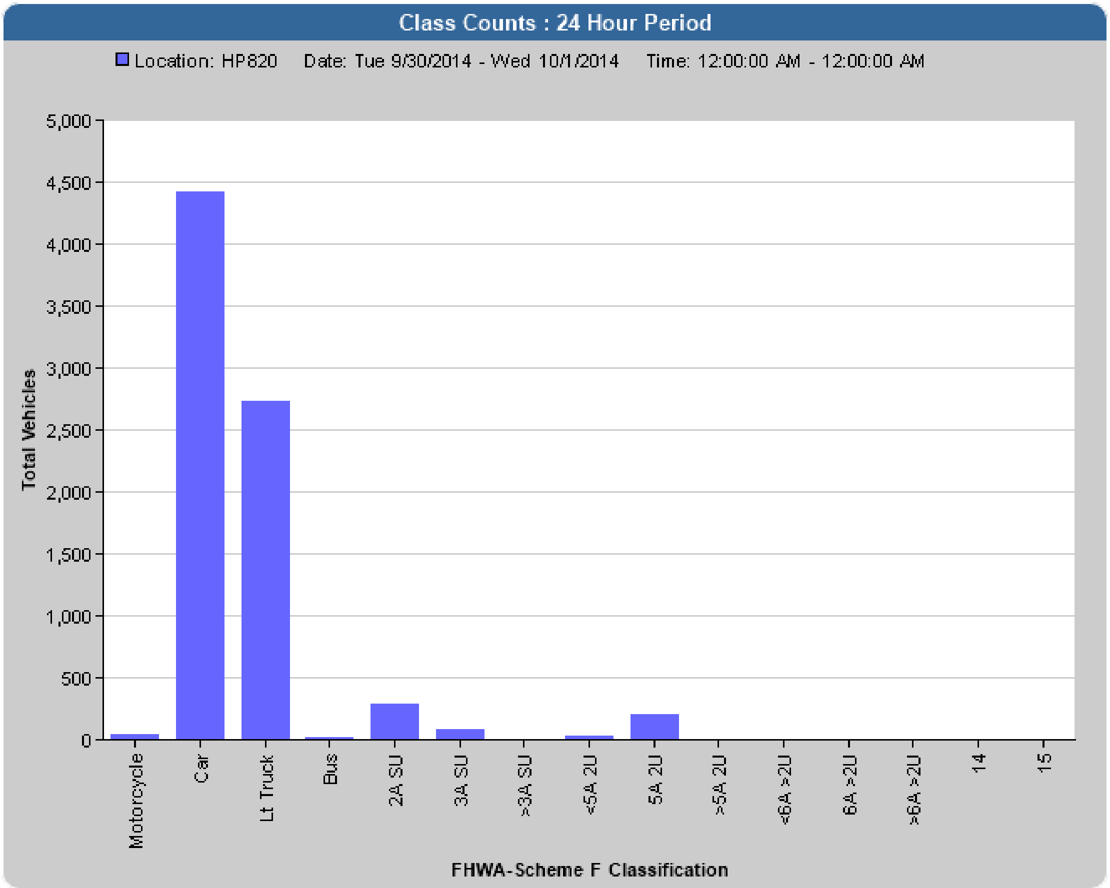


Figure 6.4: Example of Vehicle Class Distribution Based on TDMS Database in a 24-Hour Period

In the TDMS data, all vehicles are categorized based on the FHWA's standardized vehicle classification system (Scheme F) as shown in Table 6.1 (TxDOT, 2016). The TDMS stations provide vehicle-class distribution within a 24-hour period. In the example shown in Figure 6.4, fifteen vehicle classes are counted over a whole day. The total traffic volume (all classes) and percentage of each vehicle class are recorded by the TDMS station as well. Using this vehicle classification scheme, vehicles classified between Class 5 to Class 13 are considered truck.

The TDMS data also contains the following information for each station: location ID, county, community, functional class, and axle factor group. The location ID and roadway functional class were used in the following data processing and estimation algorithm.

Table 6.1: FHWA vehicle classification (Scheme F)

Vehicle Class	Vehicle Type
1	Motorcycles
2	Passenger Cars
3	Other Two-Axle, Four-Tire, Single-Unit Vehicle
4	Buses
5	Two-Axle, Six-Tire, Single-Unit Trucks
6	Three-Axle, Single-Unit Trucks
7	Four or More Axles, Single-Unit Trucks
8	Four or Fewer Axles, Single Trailer Trucks
9	Five-Axle, Single Trailer Trucks
10	Six or More Axles, Single Trailer Trucks
11	Five or Fewer Axles, Multi-Trailer Trucks
12	Six-Axle, Multi-Trailer Trucks
13	Seven or More Axles, Multi-Trailer Trucks
14	Will be defined by DOT personnel for special studies
15	Will by default identify any vehicle that does not conform to the classification criteria for Class 1 through Class 14

6.1.4 Data Screening and Map Matching

The research team developed a MATLAB program to extract useful data and information from the downloaded TDMS data. The coordinates of observation stations were assigned to the TDMS data according to location ID.

Next, the station data acquired from TDMS are mapped to appropriate links. The research team implemented a simple method for matching links and TDMS stations. It first calculated the perpendicular distances from each station to each link based on their coordinates. Then the traffic volume and screened information from the TDMS station were assigned to the link with the nearest perpendicular distance. In this method, freight network links were assumed to be straight lines. This approximation is reasonable when those links are short enough. The whole process is depicted in the simplified flowchart shown in Figure 6.5.

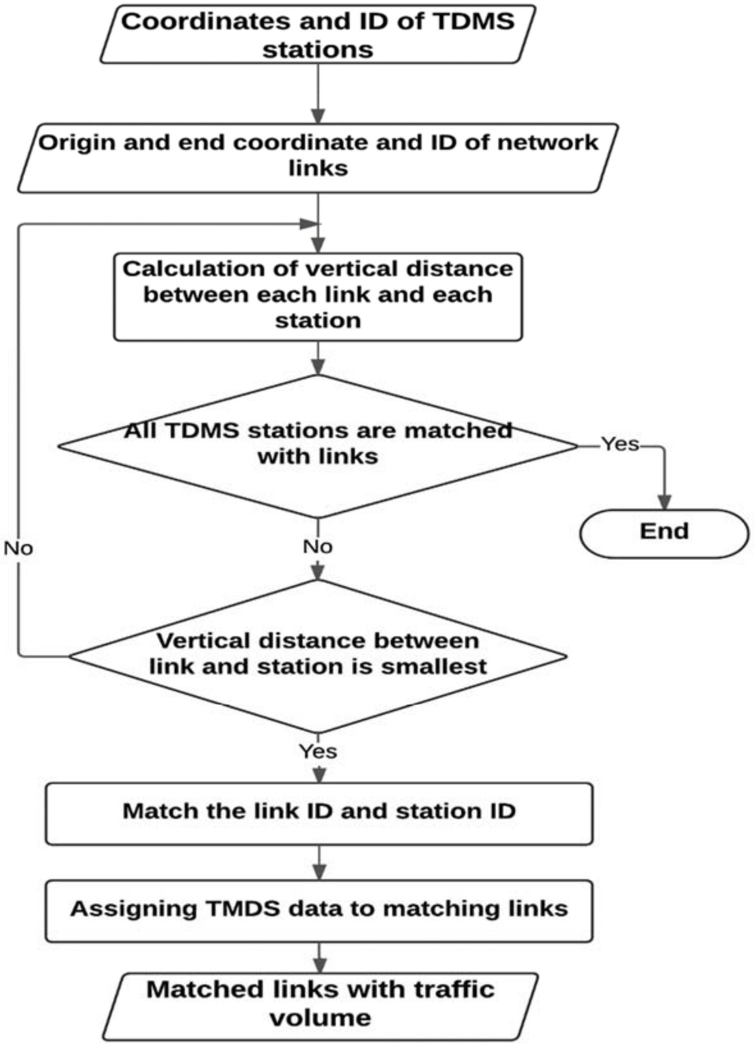


Figure 6.5: Process of Matching TDMS Data and Network Links

6.2 Estimation of Truck Flow

6.2.1 Functional Class Transformation

The created Texas freight network has 16,170 links, which exceeds the number of TDMS stations. To estimate truck flow on those links without TDMS stations, roadway functional class was as an important criterion. However, the definitions of roadway functional classes used by TDMS differ from those used by the freight network. Therefore, a functional class transformation was needed so that TDMS data could be used to estimate the traffic volume on the freight network. TDMS uses the USDOT's functional class criteria, which include the seven roadway functional classes shown in Table 6.2 (USDOT, 2008).

Table 6.2: Description of TDMS roadway functional classes

Functional Class	Description
Class 1	Interstate
Class 2	Other Expressway
Class 3	Other Principal Arterial
Class 4	Minor Arterial
Class 5	Major Collector
Class 6	Minor Collector
Class 7	Local

TxDOT's Statewide Analysis Model version 3 (SAM-V3) was used to create the freight network. SAM has 13 functional classes as shown in Table 6.3 (TxDOT, 2013).

Table 6.3: Description of SAM roadway functional classes

Functional Class	Description
Class 0	Centroid Connector
Class 1	Rural Interstate
Class 2	Rural Principal Arterial
Class 6	Rural Minor Arterial
Class 7	Rural Major Collector
Class 8	Rural Minor Collector
Class 9	Rural Local
Class 11	Urban Interstate
Class 12	Urban Freeway Express
Class 14	Other Urban Principal Arterial
Class 16	Urban Minor Arterial
Class 17	Urban Collector
Class 19	Urban Local

The research team checked the description of those functional classes to identify the correspondence between TDMS and SAM roadway functional classes. The conversion of functional class from SAM to TDMS is shown in Table 6.4.

Table 6.4: Conversion of functional class between TDMS and SAM

TDMS Functional Class	Description	SAM Functional Class	Description
Class 1	Interstate	Class 1	Rural Interstate
		Class 11	Urban Interstate
Class 2	Other Expressway	Class 12	Urban Freeway Express
Class 3	Other Principal Arterial	Class 2	Rural Principal Arterial
		Class 14	Other Urban Principal Arterial
Class 4	Minor Arterial	Class 6	Rural Minor Arterial
		Class 16	Urban Minor Arterial
Class 5	Major Collector	Class 17	Urban Collector
		Class 7	Rural Major Collector
		Class 0	Centroid Connector
Class 6	Minor Collector	Class 8	Rural Minor Collector
Class 7	Local	Class 9	Rural Local
		Class 19	Urban Local

6.2.2 Estimation Algorithm

The research team developed an algorithm to estimate the traffic volume on those links without TDMS stations. This algorithm iteratively assigned traffic volume data to those links without TDMS stations (unassigned links) based on either the traffic volume of nearby TDMS stations (when TDMS stations are located within a 5-mile radius from the middle point of the unassigned link) or the traffic volume of nearby assigned links (when no TDMS stations are available in the 5-mile circle) until all links were assigned with traffic volume data.

When using the data from nearby stations, the data from stations with the same functional class as the non-assigned links was used first. (This is why the functional class used by TDMS and the freight network need to be converted to the same scheme.)

The 5-mile radius is called the *distance factor* and it can be modified. Actually, to make sure every link is assigned with a traffic volume, the distance factor was multiplied by 1.5 every five loops when the estimation method was implemented for this task.

The example shown in Figure 6.6 demonstrates how the estimation method works. Links 1 through 4 (shown as blue lines) were matched with corresponding TDMS stations (S1, S2, S3, and S4). Links 5 and 6 (shown as green lines) cannot be matched with TDMS stations directly, so they were assigned with traffic data from TDMS stations inside the 5-mile range area from their midpoints. (The average of traffic data from S1 and S2 were assigned to link 5, and that of S3 and S4 were assigned to link 6). As there is no TDMS station located in the 5-mile range from the midpoint of link 7 (the red line), it was assigned with traffic data from the two nearest assigned links (assigned link 1 and assigned link 2).

The entire algorithm is described by the flowchart shown in Figure 6.7. After implementing this algorithm, the data items associated with each freight network link included the following: distance from nearest TDMS station, traffic volume of nearest TDMS station with the same functional class and within the distance range, average traffic volume from nearest TDMS stations within the distance range, and average traffic volume from the nearest two assigned links within the distance range.

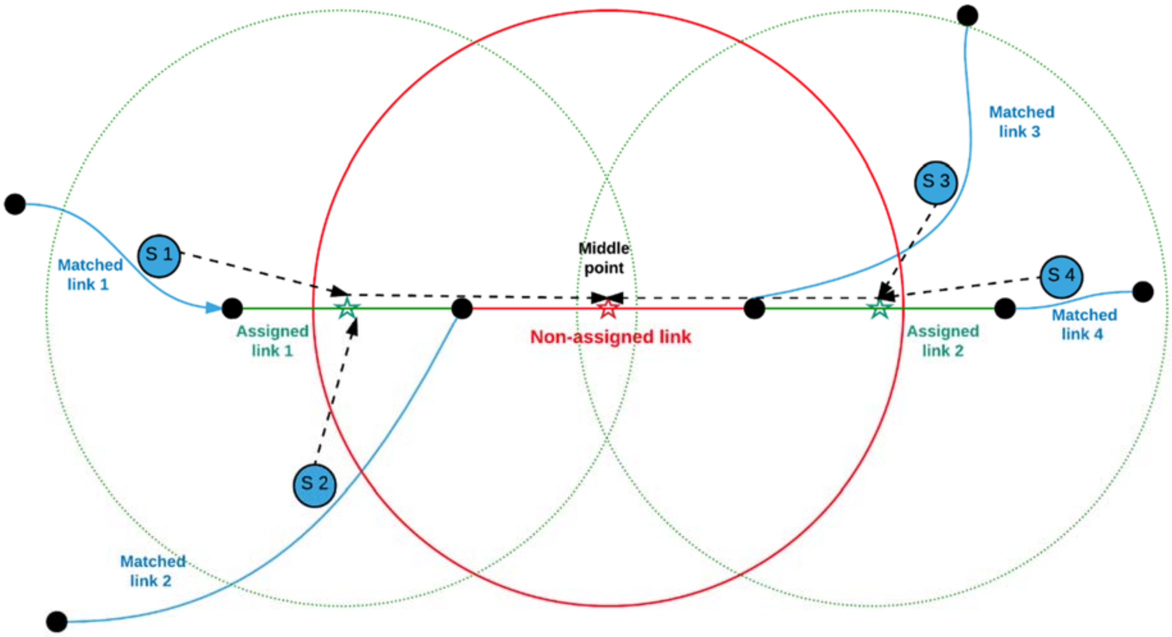


Figure 6.6: Illustration of Estimation Algorithm

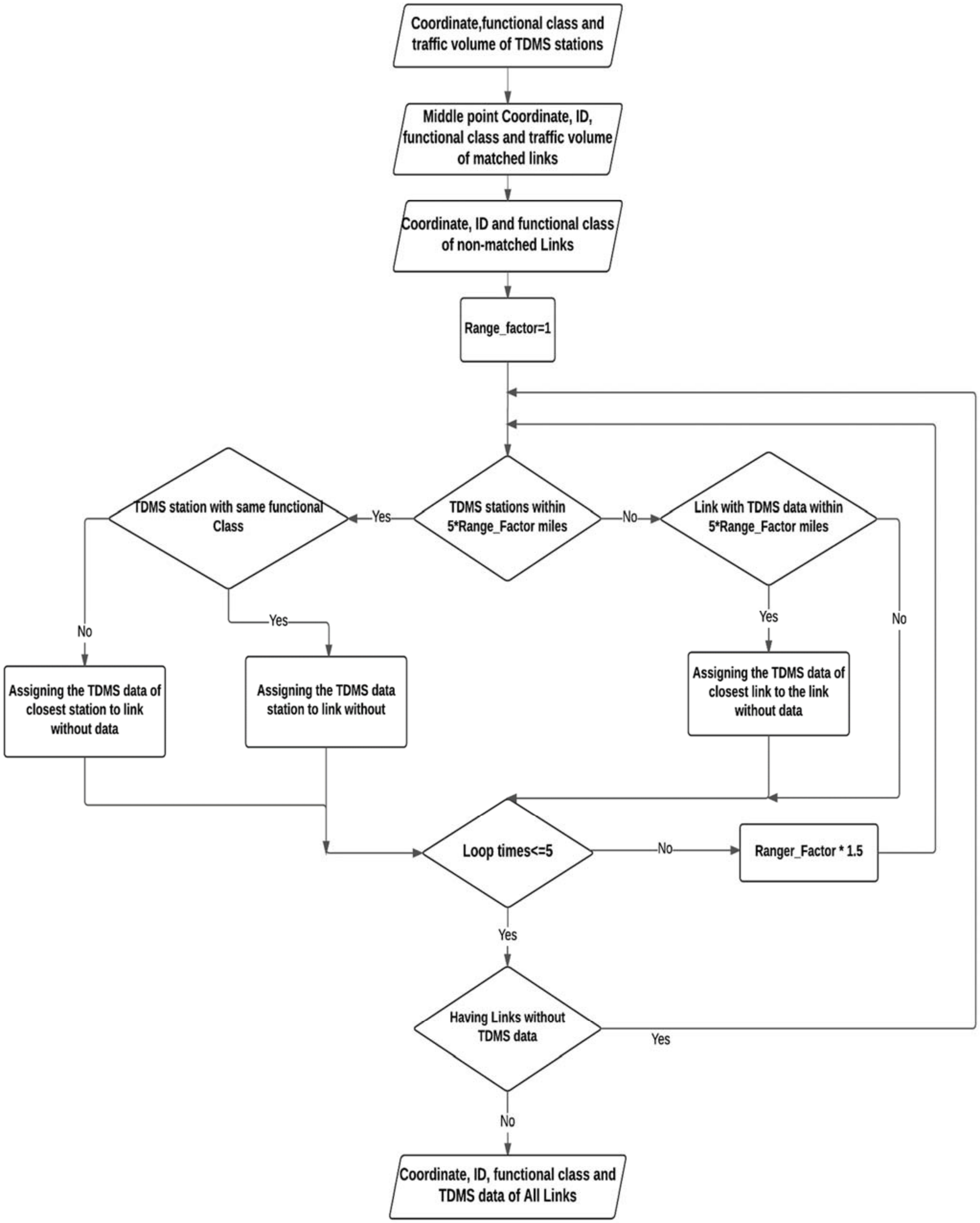


Figure 6.7: Flowchart of Estimating Traffic Volume for Links without TDMS Data

6.2.3 Estimation Results

Visualization of raw data

All traffic volume data by vehicle type was imported into ArcMap for visualization. First, two graphs with different sizes of circles, centered on a TDMS station, were drawn. The radius of the circles in Figure 6.8 and Figure 6.9 were based on the truck volume (Vehicle Class 5–Vehicle Class 13) and total traffic volume (all classes), respectively.

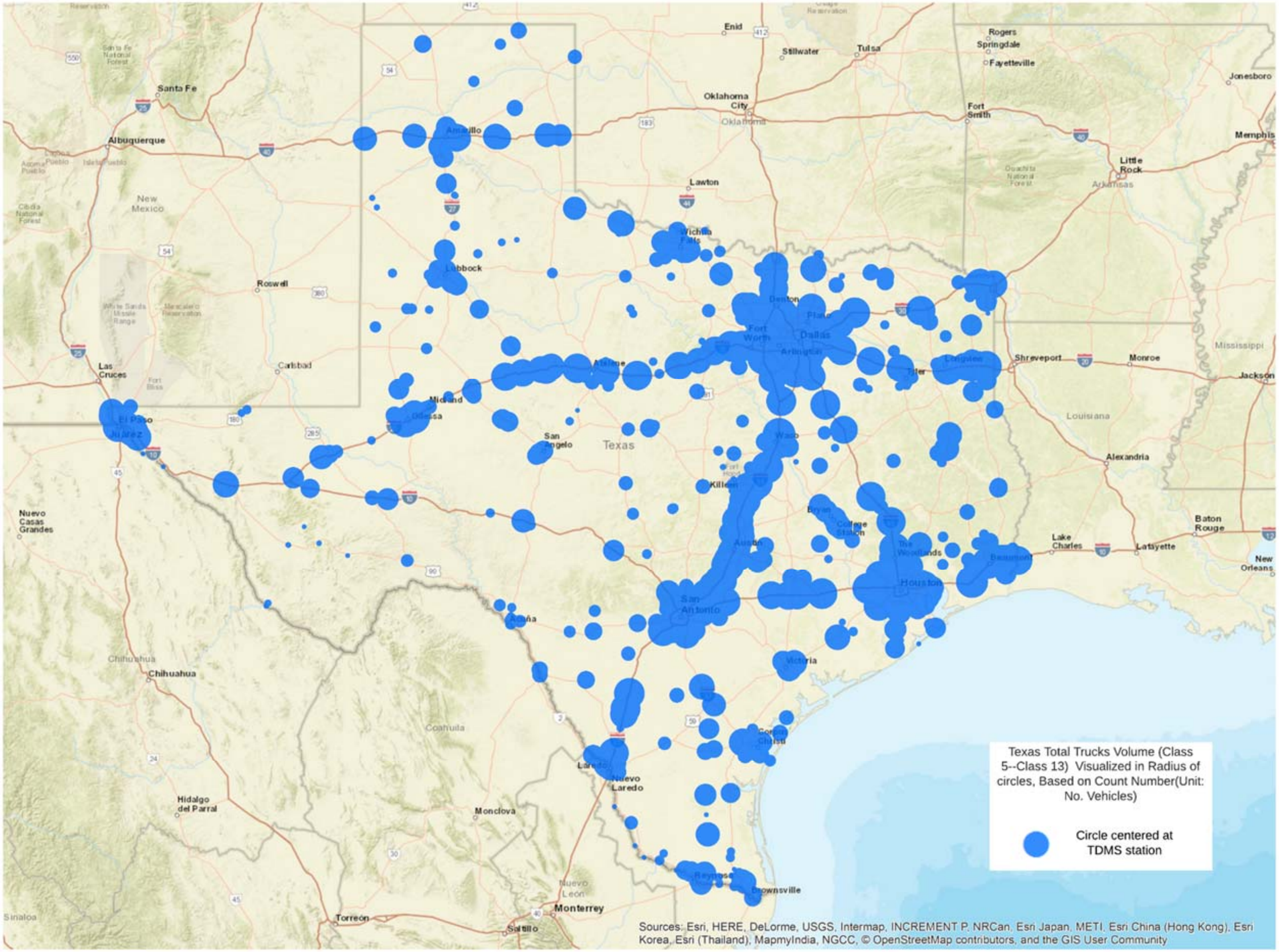


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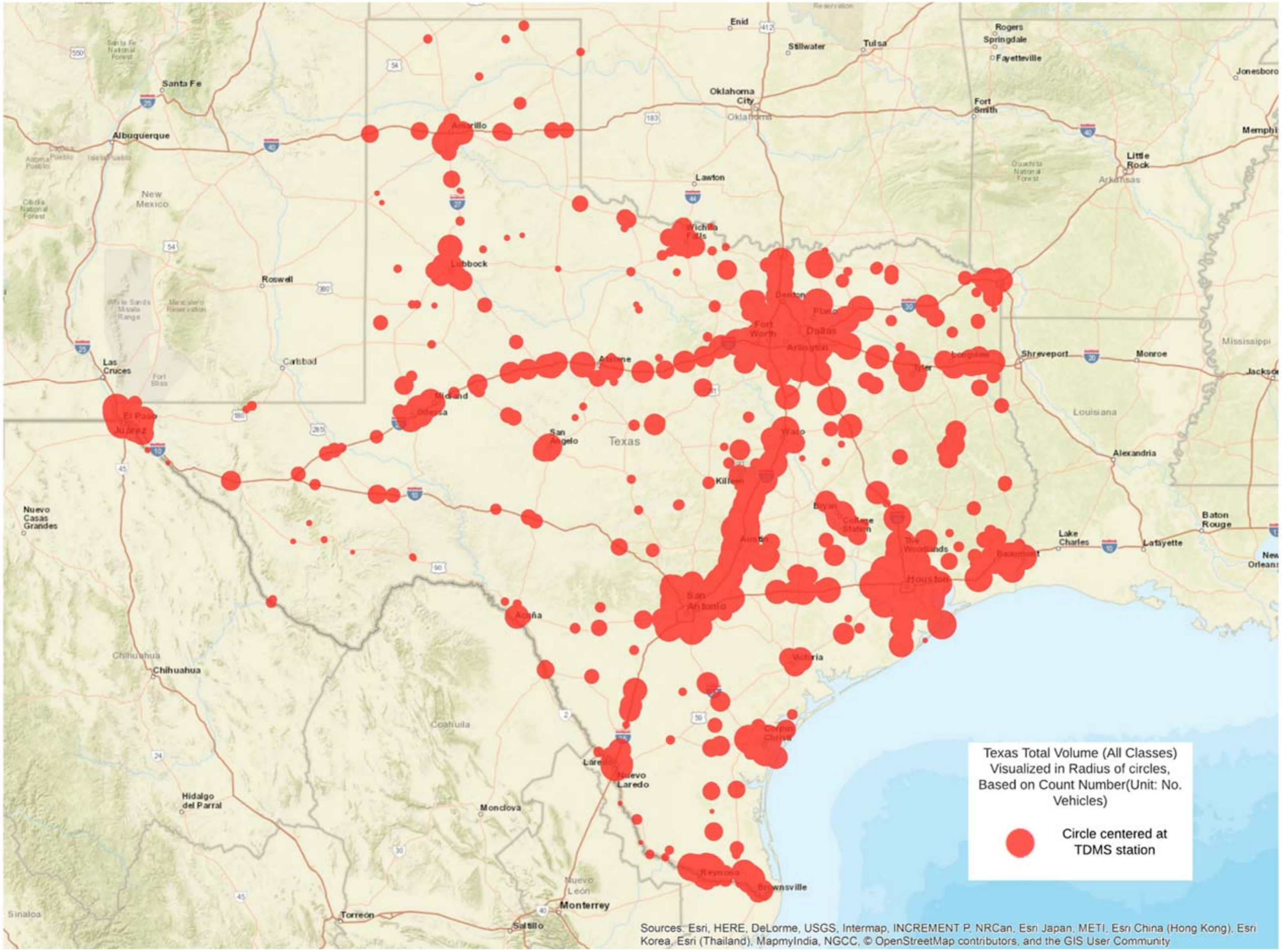
Figure 6.8: TDMS Truck Volume (Vehicle Class 5–Vehicle Class 13)



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6.9: TDMS Total Traffic Volume (All Vehicle Classes)

Visualization of estimated truck volume and total traffic volume

The research team also used ArcMap software to visually represent the total truck volume and total traffic volume based on matched and estimated link data for the freight network.

Two visualization methods were applied: color and line thickness. For color visualization, a gradual shading from green to red was used to show both total traffic volume (all vehicle classes) and truck volume (Vehicle Class 5–Vehicle Class 13), as shown in Figure 6.10 and Figure 6.11. Varying line thickness was used to illustrate both total traffic volume (all vehicle classes) and truck volume (Vehicle Class 5–Vehicle Class 13), as shown in Figure 6.12 and Figure 6.13.

These figures clearly illustrate the traffic distribution of all types of vehicles and especially trucks on the Texas freight network. They will be an important reference for comparing and examining truck flow estimation in the following sections.

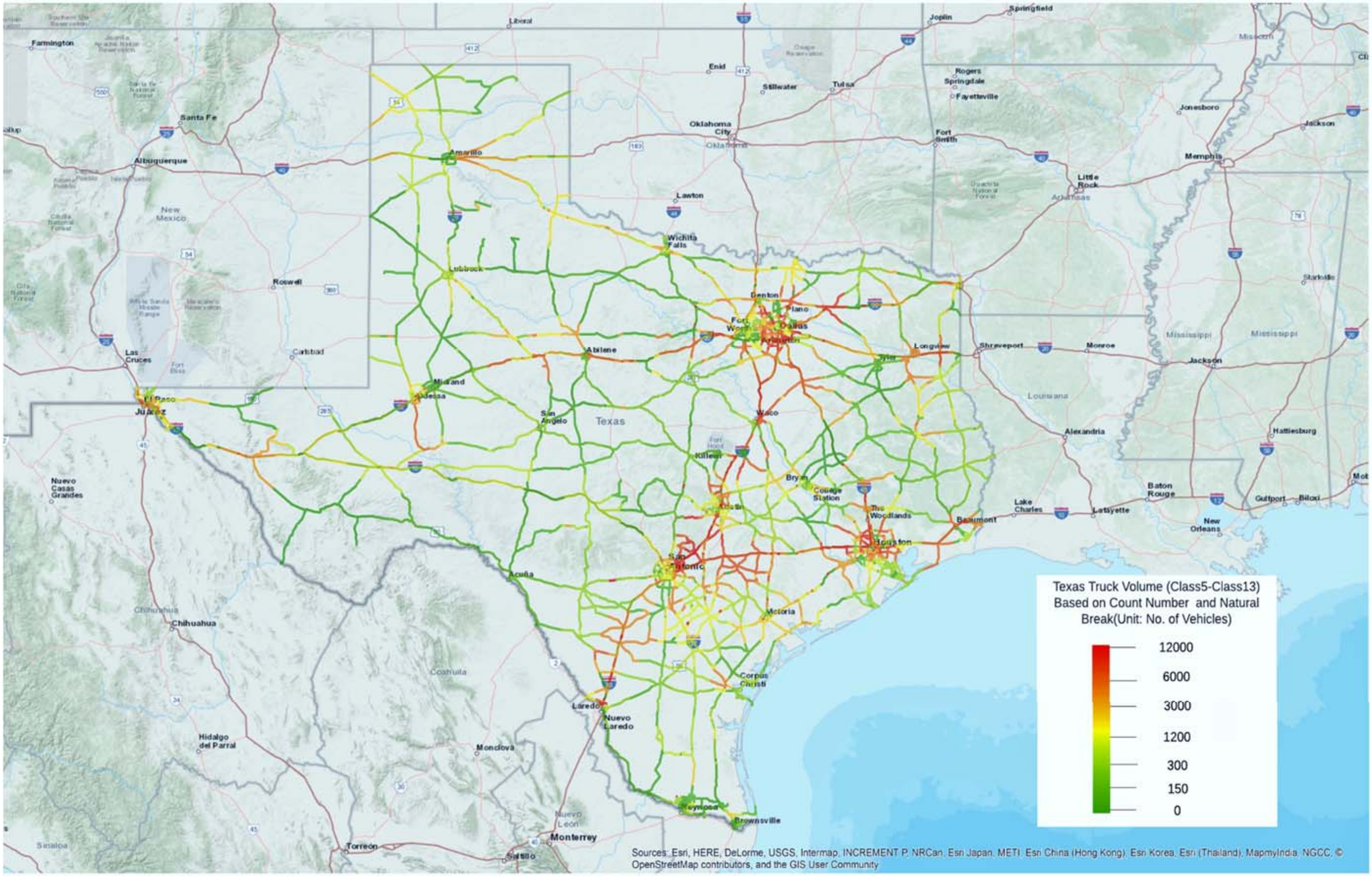


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Figure 6.10: Estimated Truck Traffic Volume (Vehicle Classes 5–Vehicle Classes 13)

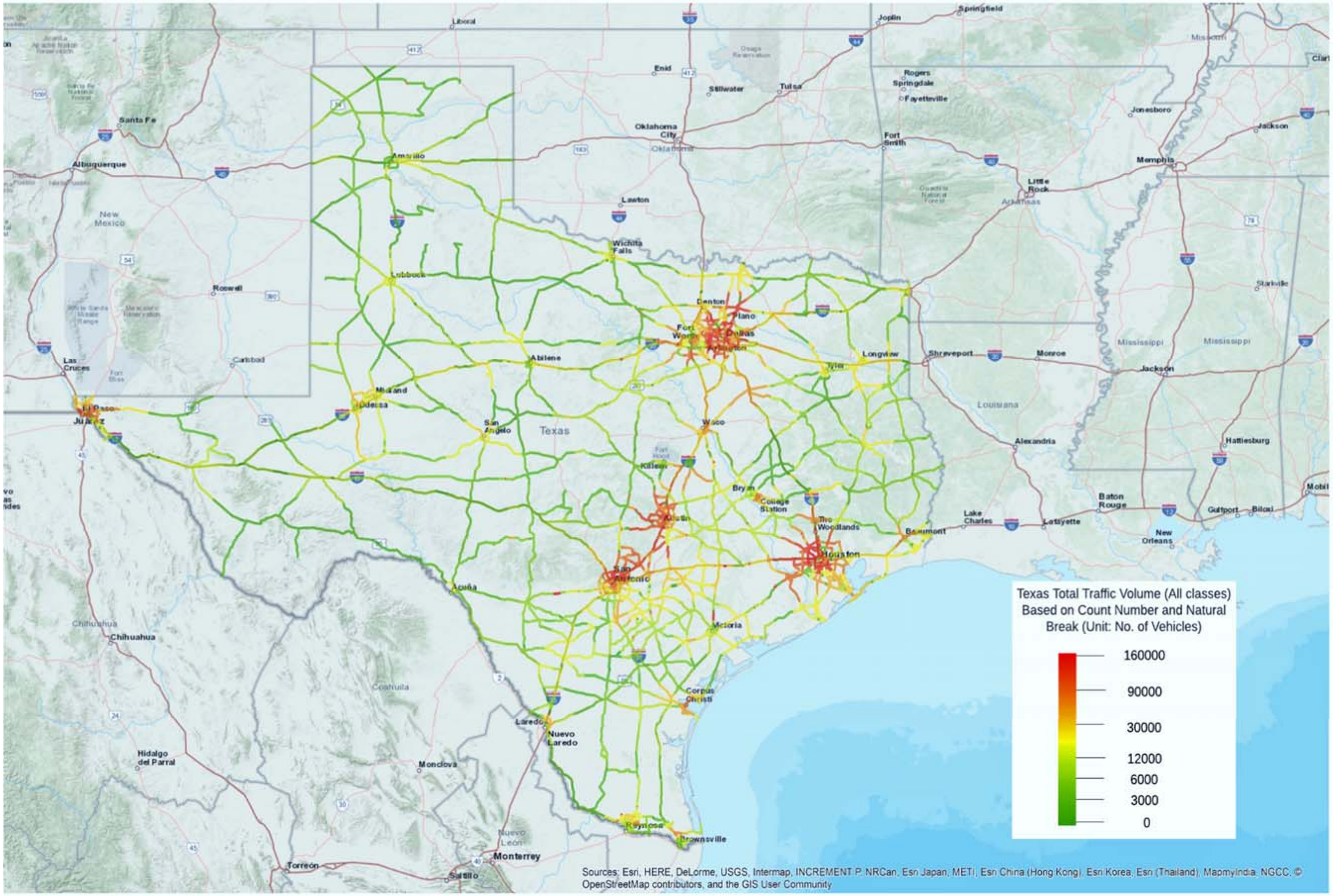

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Figure 6.11: Estimated Total Traffic Volume (All Vehicle Classes)

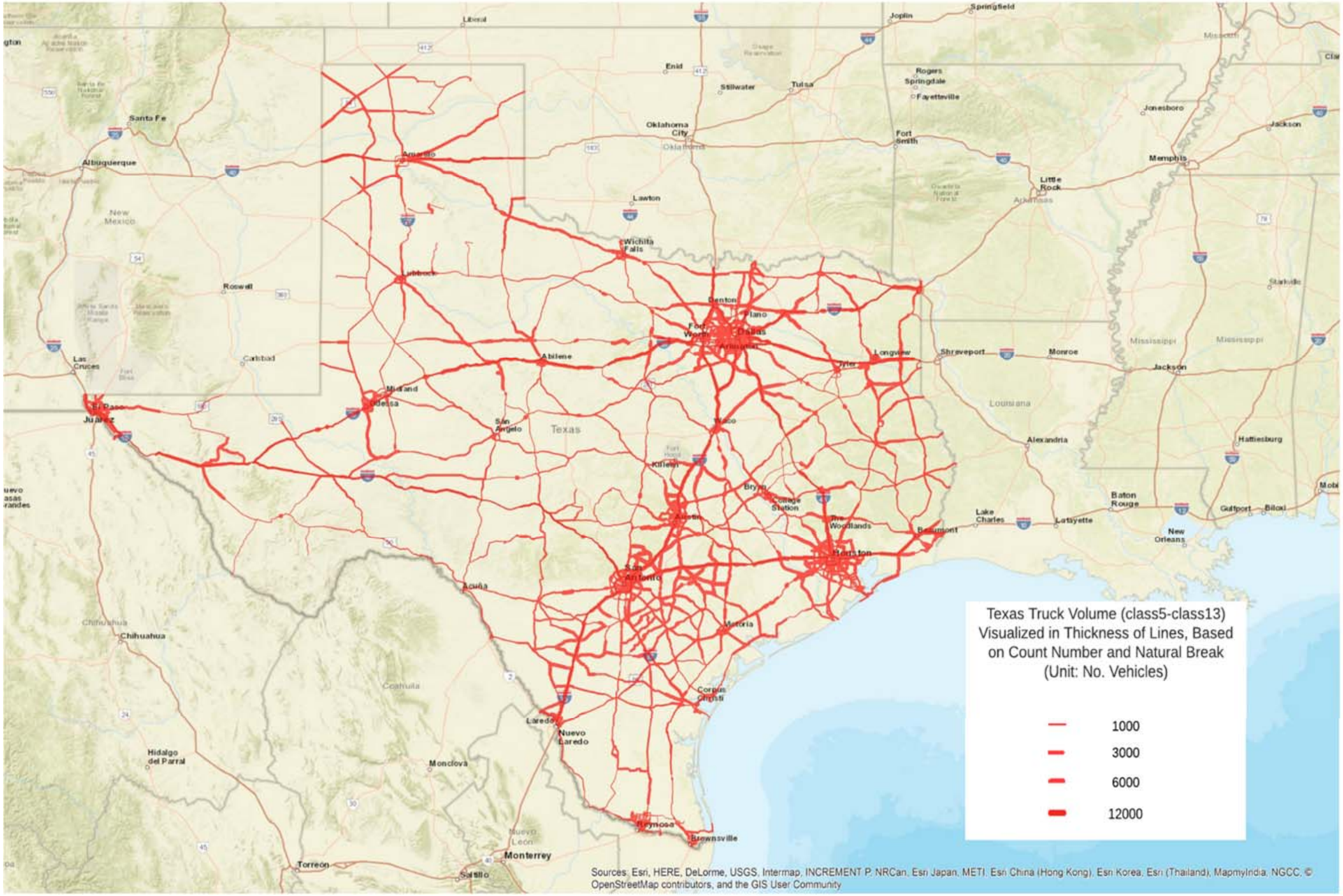
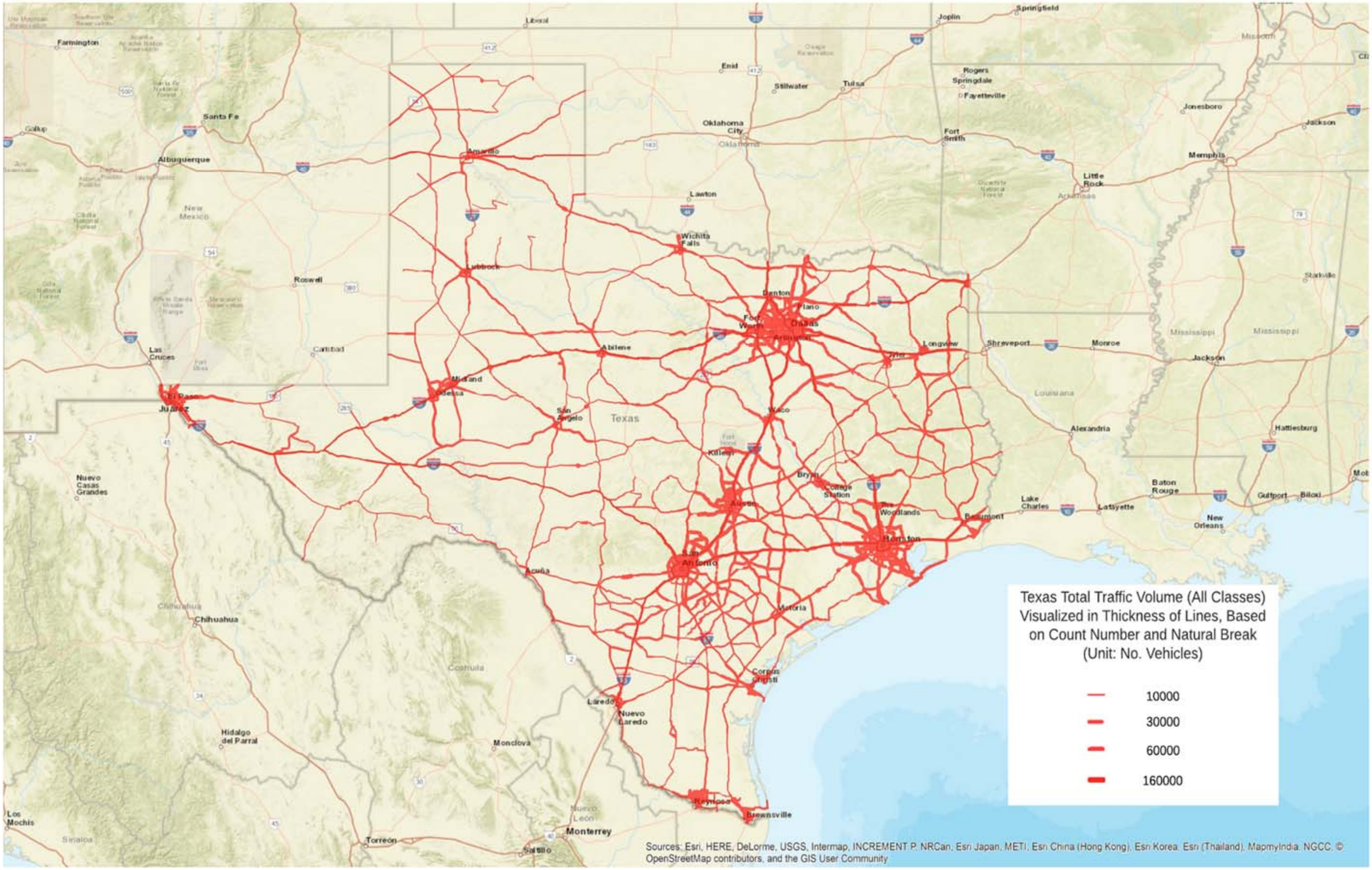


Figure 6.12: Estimated Truck Traffic Volume (Vehicle Class 5–Vehicle Class13)



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6.13: Estimated Total Traffic Volume (All Vehicle Classes)

6.3 Compare TDMS Data with Initial Assignment Results

The initial assignment results (without considering the impact of traffic congestion) were compared with the TDMS data for testing the accuracy of commodity flow estimation and identifying links that might be assigned with inappropriate amount of commodity truck volume. Both TDMS raw data and TDMS-based truck volume estimation were used to compare with the total truck volumes estimated from previous commodity flow estimation models.

6.3.1 Truck Volume Comparison between Commodity-based Estimation and TDMS Data-based Estimation

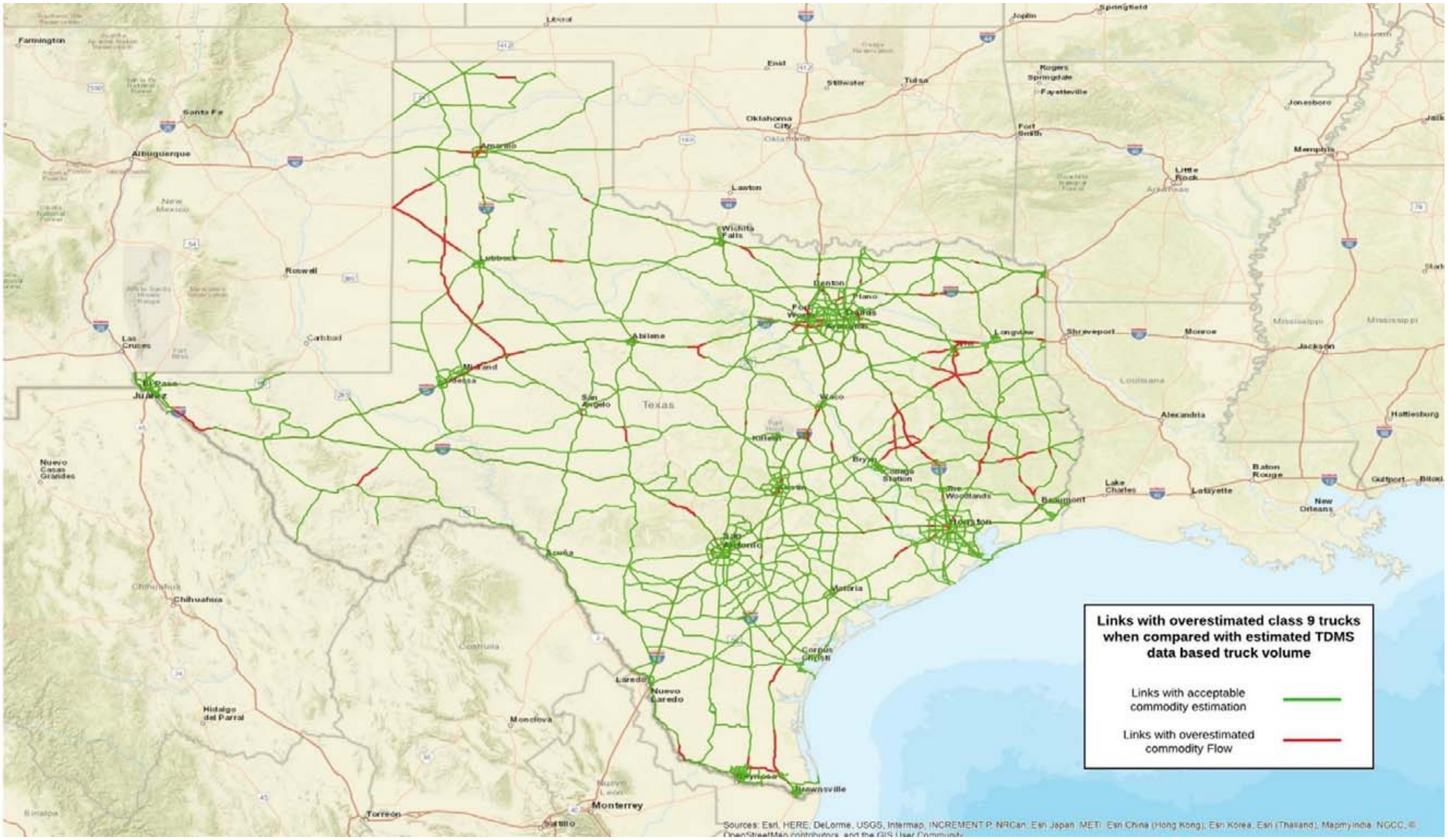
The research team summed up the estimated truck volume from all commodities in the commodity flow assignment model. The commodity-based truck flow only contains vehicle Class 6 and vehicle Class 9, as the research team estimated that most of the commodities studied in this project are transported using these two classes of vehicles (see Figures 5.55 and 5.56). The research team made three types of comparisons (see Table 6.5) between commodity-based truck flow estimation and both the raw and estimated TDMS-data based traffic volume.

Table 6.5: Truck flow comparisons

Comparison group number	**Estimated commodity-based truck flow**		**TDMS data-based traffic volume (raw and estimated)**
Group 1	Class 9	**compare with**	Class 9
Group 2	Class 6 + Class 9		Class 6 + Class 9
Group 3	Class 6 + Class 9		Total truck volume (sum of class 5 to class 13)

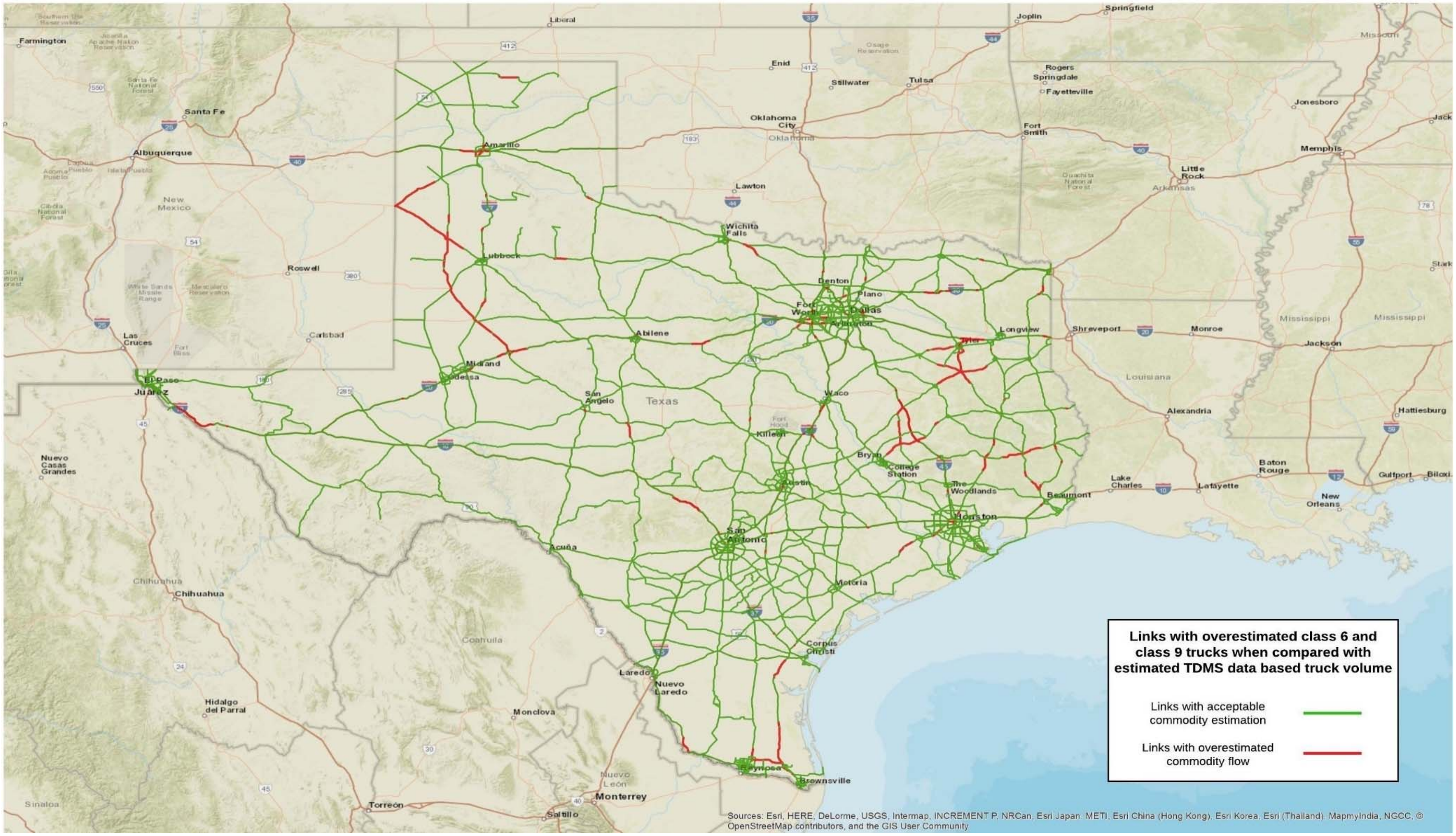
Of the 16,170 links in the created freight network (refer to Section 4.3.1), 11,848 of them were assigned with commodity flow. The research team first matched the TDMS data-based link traffic volume estimation with commodity-based truck flow estimation based on link ID in the freight network. Those links that were not assigned a commodity flow or didn’t have an estimated TDMS-based traffic volume were excluded from the comparison. Then, the difference between two sources for each link was calculated. The commodity-based flow estimation model estimated the number of trucks moving on each link for 10 commodities (as covered in previous Chapter), while the TDMS data were for all commodities since traffic counts data don’t impart any information regarding commodities being transported. Therefore, TDMS data can only be used as an upper bound when compared with commodity-based flow estimation. If on certain links the commodity-based flow estimation is larger than corresponding TDMS data-based traffic volume, then the commodity-based model may overestimate the trucks flows moving on those links (called *overestimated links* hereafter).

The comparison results show that in the Group 1 comparison, i.e., when comparing commodity-based Class 9 truck trips with TDMS-based Class 9 truck trips, 1,136 links are overestimated. In the Group 2 comparison, 989 links are overestimated (Class 6 + Class 9), and 499 links are overestimated in Group 3 comparison (total truck trips). The locations of those overestimated links are shown in Figure 6.14 to Figure 6.16.



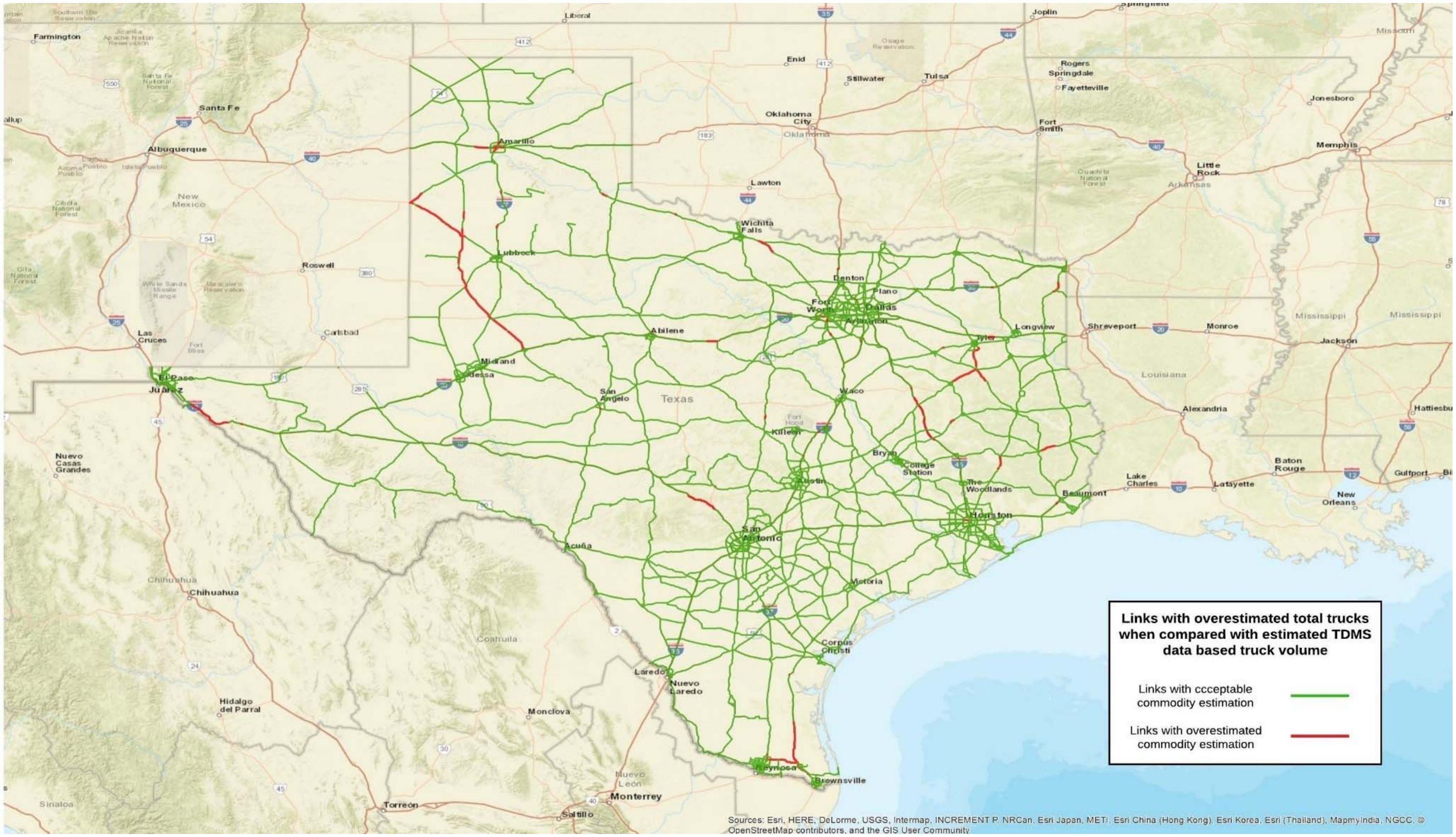
Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6.14: Links with Overestimated Class 9 Trucks when Compared with Estimated TDMS Data-Based Truck Volume



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6.15: Links with Overestimated Class 6 and Class 9 Trucks when Compared with Estimated TDMS Data Based Truck Volume



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

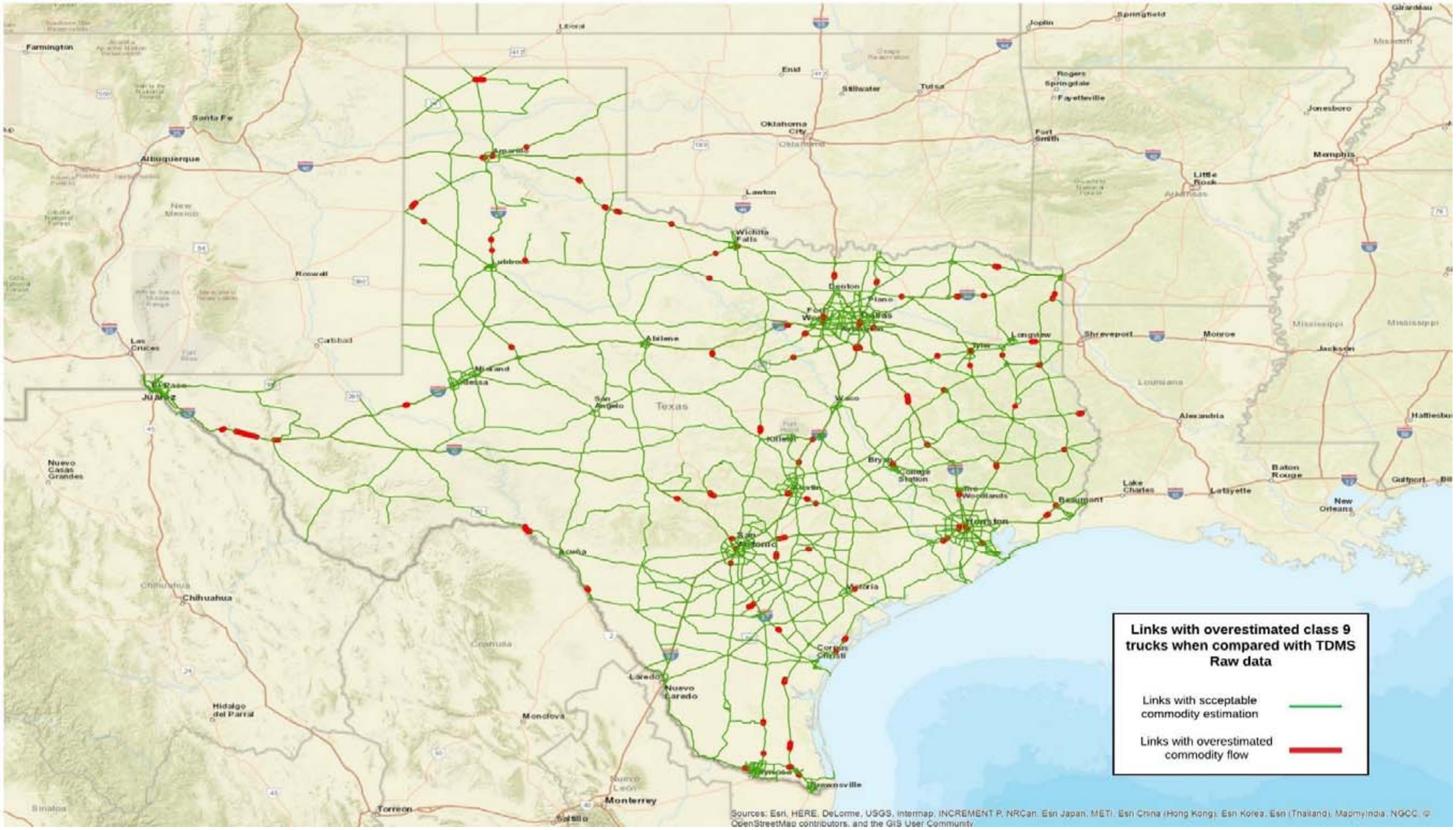
Figure 6.16: Links with Overestimated Total Number of Trucks when Compared with Estimated TDMS Data Based Truck Volume

6.3.2 Truck Volume Comparison between Commodity-based Estimation and TDMS Raw Data

Since there might be random errors in the process of estimating truck flows based on TDMS data, the comparisons in the previous section might not accurately reflect all overestimated links. Therefore, the team compared TDMS raw data and commodity-based truck flow estimation. After map matching, 849 TDMS stations were matched with appropriate links in the freight network. Of those, 541 comparable links were identified after excluding those links that are not assigned with commodity flow or don’t have estimated TDMS-based traffic volume. The comparison results are shown in Table 6.6. Those overestimated links are shown in Figures 6.17 through 6.19.

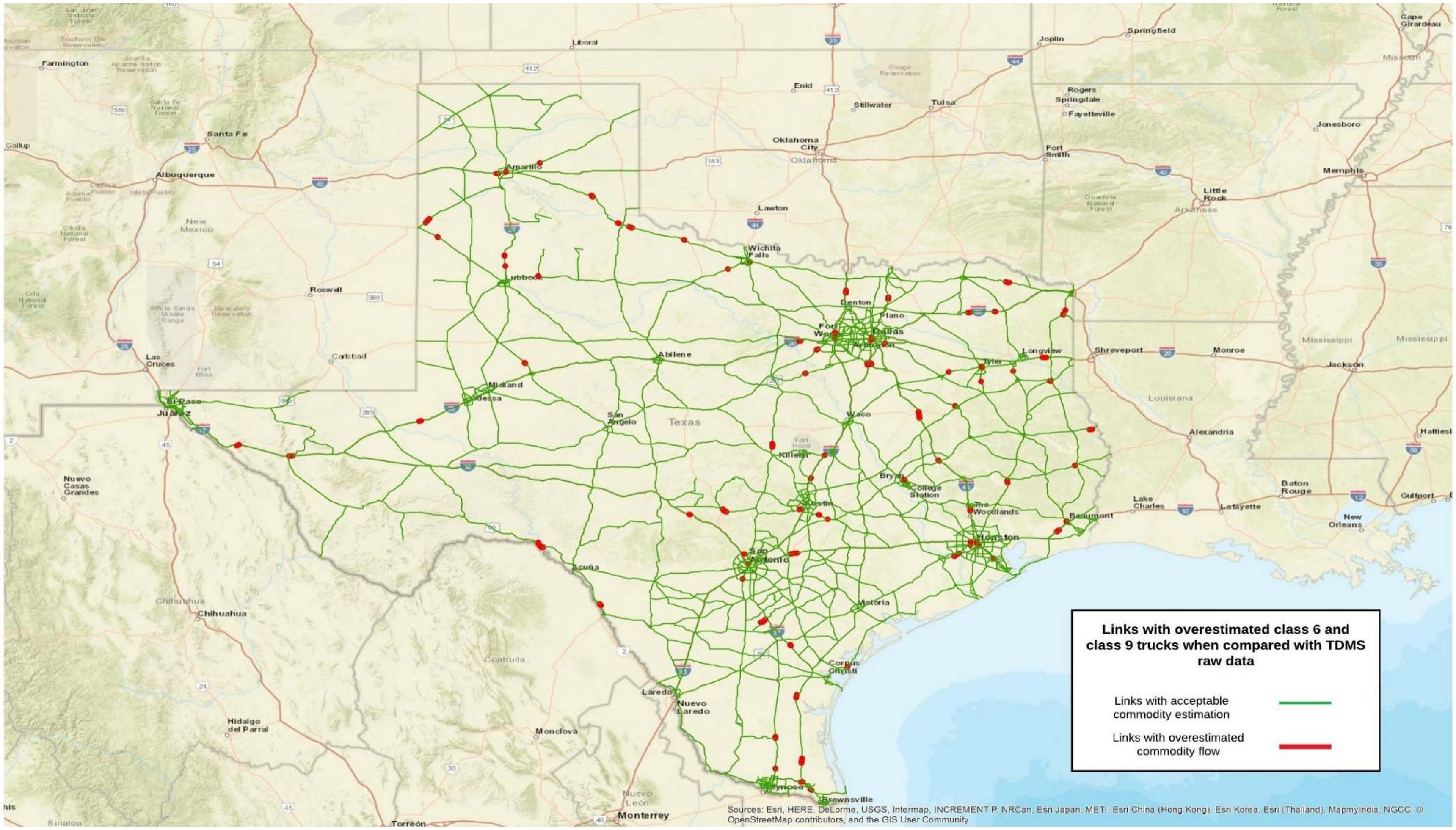
Table 6.6: Number of overestimated links when compared with raw TDMS data

Comparison Group	Number of Overestimated Links
Group 1 (Class 9)	107
Group 2 (Class 6 + Class 9)	90
Group 3 (Total)	49



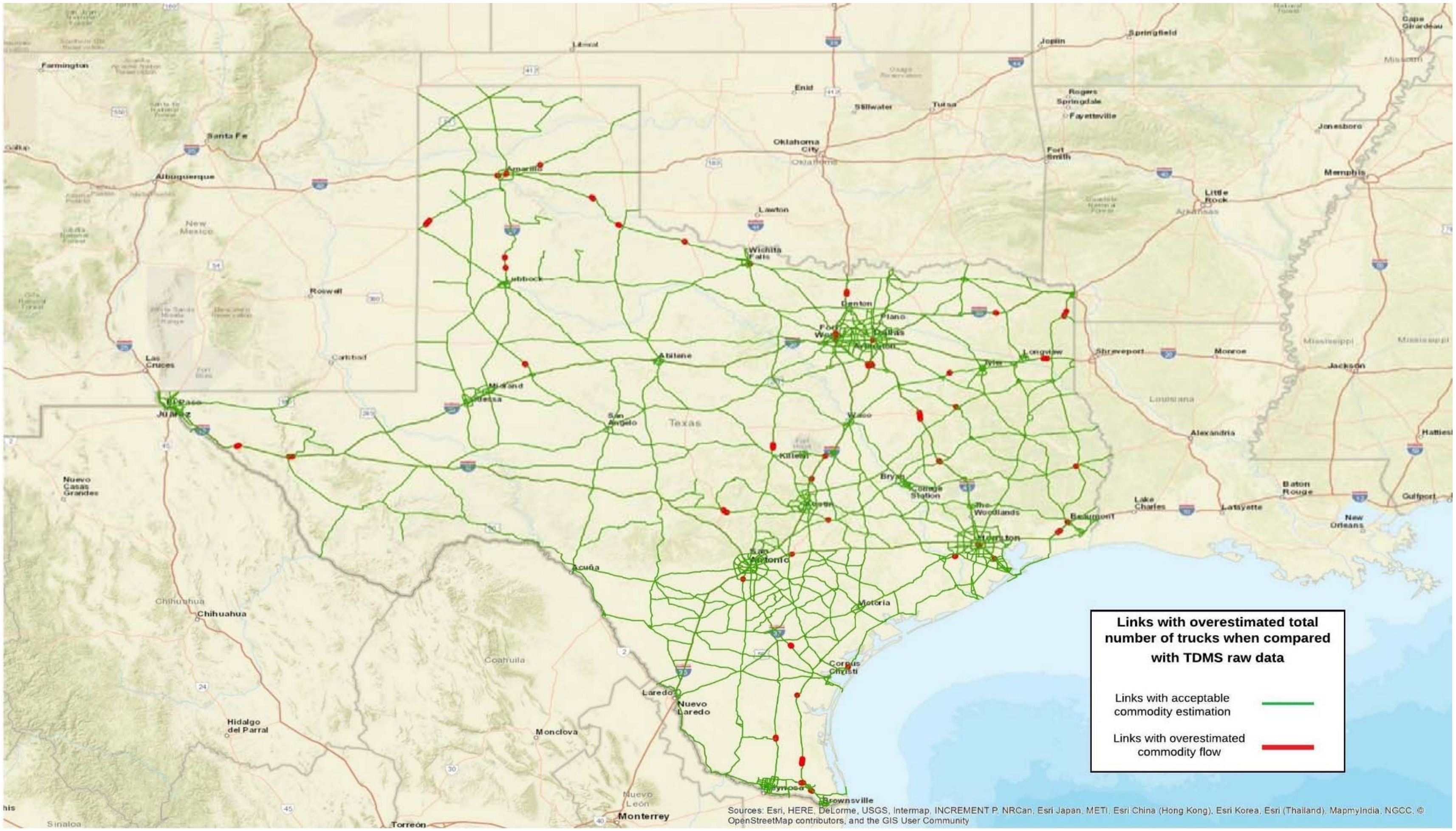
Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6.17: Links with Overestimated Class 9 Trucks when Compared with TDMS Raw Data



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6.18: Links with Overestimated Class 6 and Class 9 Trucks when Compared with TDMS Raw Data



Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Figure 6.19: Links with Overestimated Total Number of Trucks when Compared with TDMS Raw Data

6.3.3 Uncertainty of TDMS Raw Data

As mentioned in Section 6.1.2, the TDMS raw data was recorded by collecting traffic volume information from stations on a random date in between 2013 and 2014. Therefore, uncertainties were associated with TDMS raw data. The research team developed a statistic to measure the magnitude of uncertainty of TDMS data.

Traffic volumes were divided into 46 intervals from 0 to 11500 and each interval had a range of 250 (i.e., 0-250, 250-500, 500-750, ... , 11000-11250, 11250-11500). The coefficient of variance of individual interval for TDMS Class 9 volume, sum of Class 6 and Class 9, and total truck volume (Class 5–Class 13) were calculated. The graph of coefficient of variance versus associated range for volume of Class 9 only, sum of Class 6 and Class 9 truck volume, and total truck volume are shown in Figures 6.20 through 6.22. The coefficients for empty range and the range with only one traffic data point were ignored in those figures.

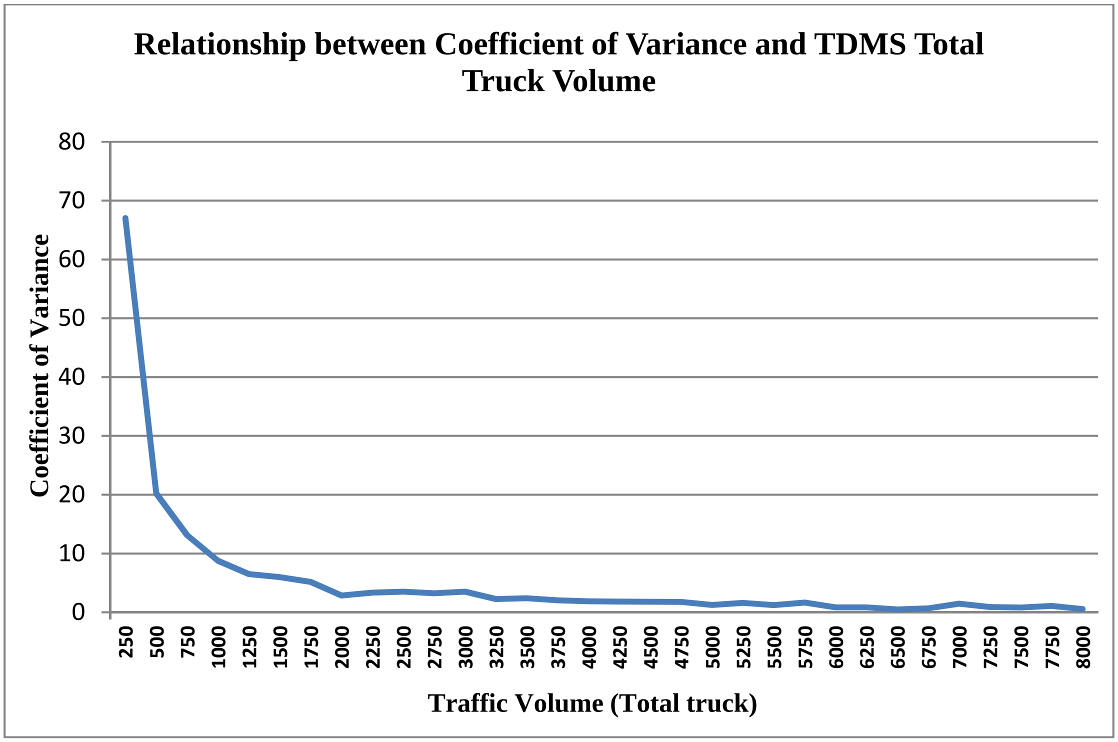


Figure 6.20: Relationship between TDMS Total Truck Volume and Its Coefficient of Variance

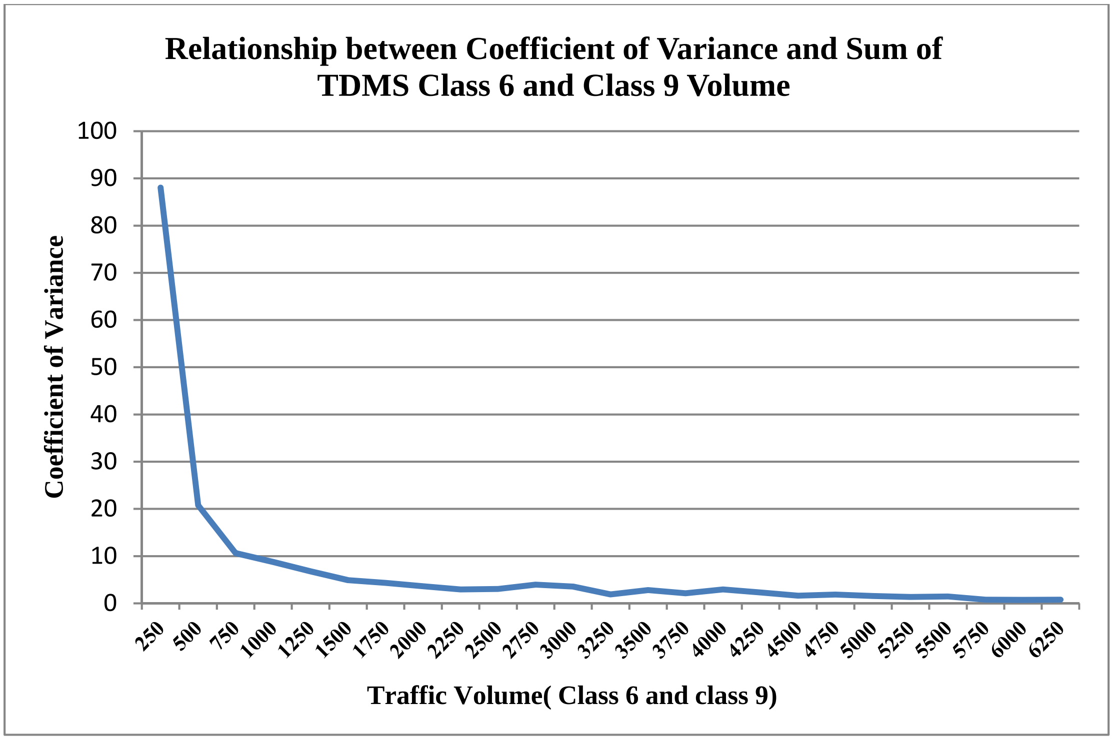


Figure 6.21: Relationship between Sum of TDMS Class 6 and Class 9 Volume and Its Coefficient of Variance

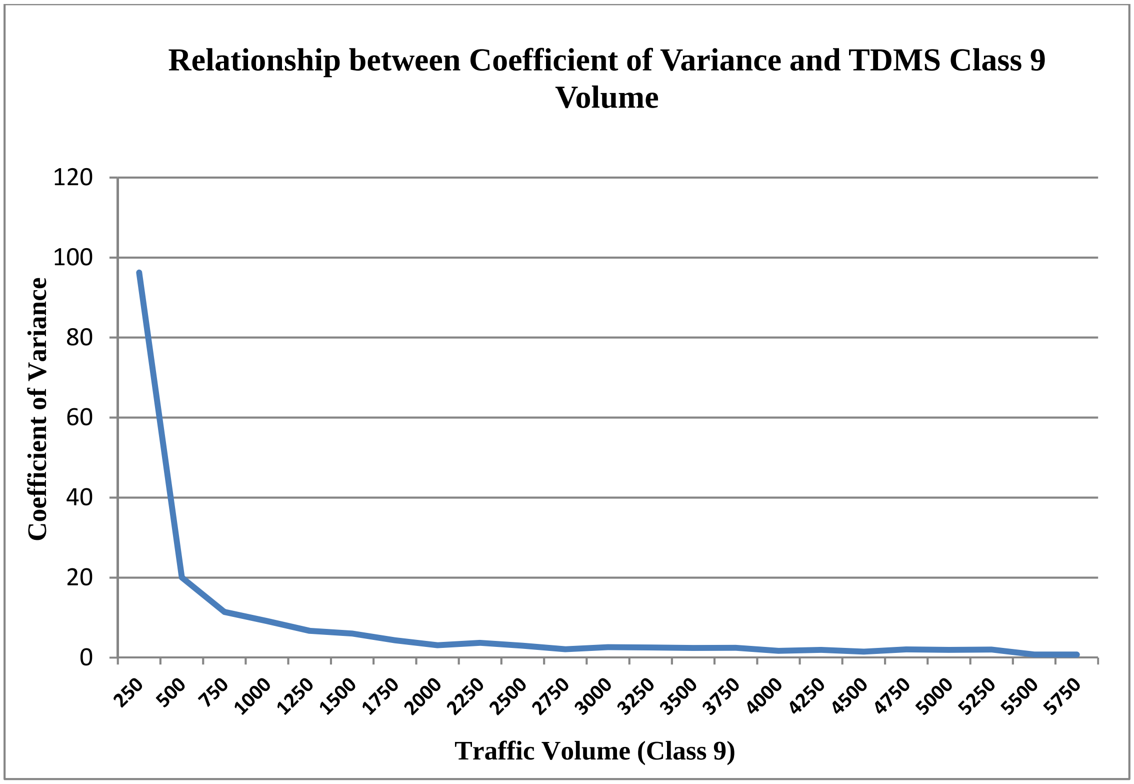


Figure 6.22: Relationship between TDMS Class 9 Volume and Its Coefficient of Variance

Figures 6.20 through 6.22 show a helpful trend: the variability of TDMS data decreases when the traffic volume increases. This indicates that the uncertainty of TDMS traffic data is relatively high when the traffic volume is low. Based on this observation, the research team developed a factor λ (lambda) that is used to test the effect of the uncertainty of TDMS data on the comparison process. This factor λ considers both the difference between TDMS traffic volume and commodity-based truck flow and the uncertainty of TDMS data. It is defined as the absolute value of difference in traffic volume from two datasets (TDMS-based and commodity-based) divided by the standard deviation of TDMS data.

$$\lambda = \frac{|V_{TDMS} - V_{commodity}|}{\sigma_{TDMS}} \tag{6.1}$$

This factor was calculated for each link. A link with higher value of λ could indicate the commodity flow estimation was more likely to have some error, since this means it had higher deviation in its denominator and/or less uncertainty of TDMS data in the numerator. Similarly, a link with a small value of λ could be considered an acceptable link even if its commodity-based flow estimation was larger than the TDMS data-based truck volume.

The values of λ for all overestimated links were in the range of 0.001 to 4.119 for Class 9 comparison, 0.001 to 4.348 for the comparison of the sum of Class 6 and Class 9 volumes, and 0.001 to 3.768 for total truck comparison. The links with highest λ value for all three comparisons are shown in Figure 6.23.

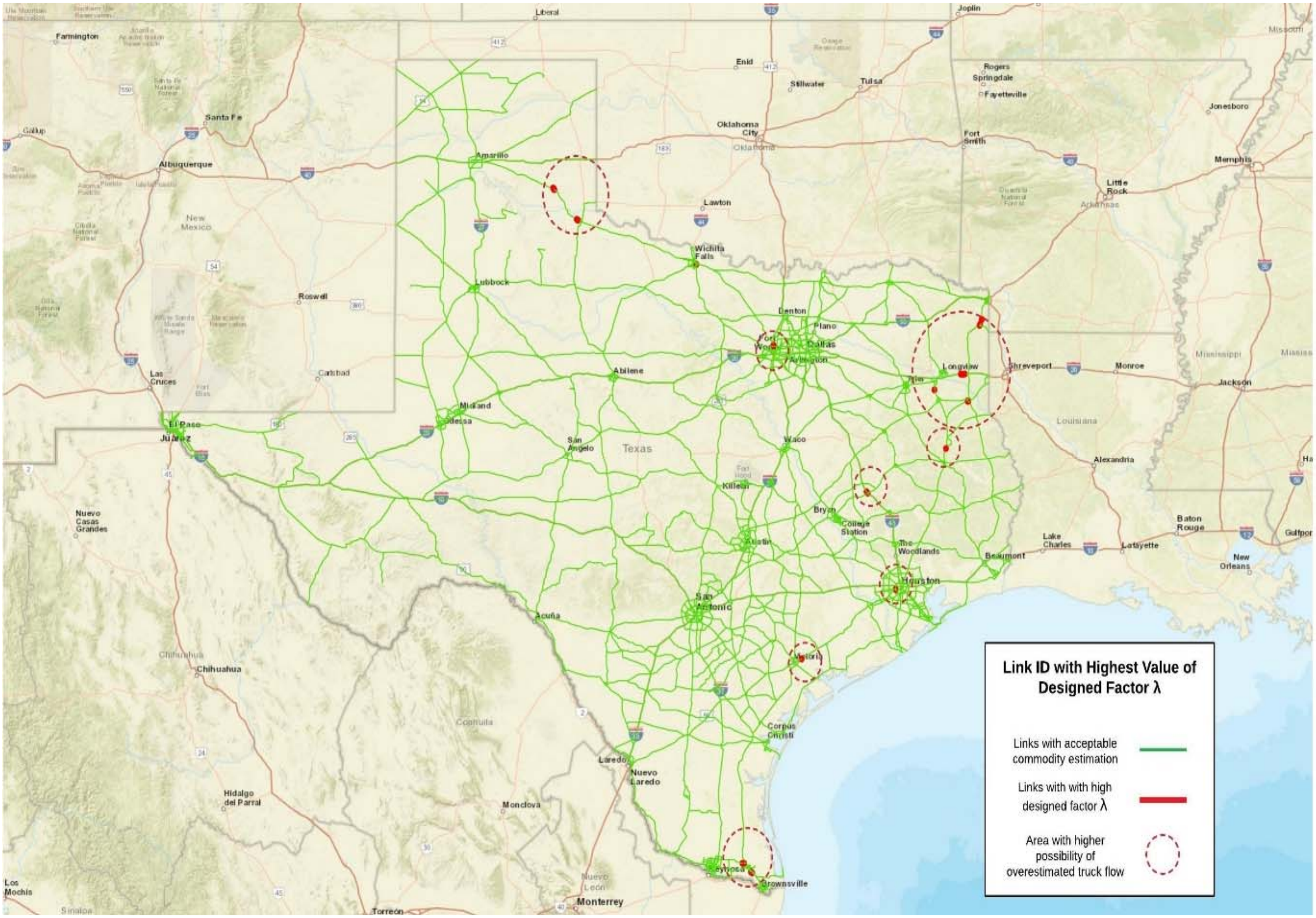


Figure 6.23: Visualization of Links with Relatively Higher Values of Factor λ for All Three Comparisons

6.3.4 Possible Reasons for Discrepancies

Due to different data structures and different scales of modeling subjects, it is impossible to make a direct one-to-one comparison between the modeling results obtained in the project with any existing databases.

The TDMS data provide link-level truck volume, but it didn't have any commodity-related information. Therefore, it could only be used as an upper bound to check against the commodity-based assignment results. As described in previous sections, the assignment results on most links are reasonable. The model developed in this project overestimated truck flows on a few links, primarily due to the roadway network used for trip assignment. This study created a network based on the Texas primary and secondary freight network and assigned commodities under study to this network. As a result, many other roadways that are not part of the Texas freight network were excluded from the assignment process. In reality, many other roadways may be used to move these commodities. In other words, we limited the route choices of those commodities and, as a result, they concentrate on those primary and secondary freight corridors, causing unreasonably high truck volumes on some links.

Another reason for these discrepancies is that during the traffic assignment, freeflow travel times were used to calculate the travel time between origin and destination and all the truck trips were assigned to the one route with the shortest travel time (i.e., the all-or-nothing traffic assignment method). This approach could cause truck flows to concentrate on some routes, while in reality they could distribute on multiple routes between the same origin and destination pair. Therefore, in the next section, the research team compared the TDMS data with link-level truck volume obtained from the new traffic assignment which considered the impact of congestion (refer to Section 4.5.2 for an overview about how impact of congestion is considered in the modeling process).

Seasonal variation could be another reason, as TDMS data is collected at different times of the year. However, if we filtered those TDMS traffic data that are calculated in a specific month, the sample size would be too small to arrive any reliable conclusion.

6.4 Compare TDMS Data with Assignment Results Considering Impact of Congestion

As mentioned above, without considering the impact of congestion (e.g., using freeflow travel time and an all-or-nothing traffic assignment method), truck flows may concentrate on some routes and cause overestimation on some links. In this section, we compared the assignment results after considering the impact of congestion with TDMS again to see if this is the case.

Three groups (as shown in Table 6.5) were compared using traffic assignment results after considering the impact of congestion and TDMS data. As mentioned, we used TDMS data as an upper bound for comparison with our analysis results. Those links with traffic assignment results greater than the corresponding TMDS traffic volumes were considered overestimated links. The number of overestimated links generated are shown in Table 6.7 and Table 6.8.

Those two tables show that the new traffic assignment generated fewer overestimated links than the original traffic assignment did for all three comparison groups.

This indicates some unreasonable link flow estimation in the original traffic assignment was eliminated by considering the impact of congestion in the modeling process.

Table 6.7: Number of overestimated links when original and new assignment results are compared with TDMS-based traffic volume estimation

	Number of Overestimated Links	
Comparison Group	**Initial Traffic Assignment**	**New Traffic Assignment**
Group 1 (Class 9)	1136	1111
Group 2 (Class 6 + Class 9)	989	969
Group 3 (Total)	499	359

Table 6.8: Number of overestimated links when original and new assignment results are compared with TDMS raw data

	Number of Overestimated Links	
Comparison Group	**Initial Traffic Assignment**	**New Traffic Assignment**
Group 1 (Class 9)	107	81
Group 2 (Class 6 + Class 9)	90	70
Group 3 (Total)	49	38

The daily traffic assignment results considering the impact of seasonal variation were not used for the comparison because those daily traffic assignment results were obtained only for peak months, while the TDMS database is populated with input from random dates. Thus, a fair comparison could not be conducted.

Chapter 7. Support Infrastructure Investment Decision-Making

This chapter demonstrates how estimates from the base model can be used to support infrastructure investment decision-making. The value of commodities moving on the road network is an important but often neglected factor when agencies make their decisions about allocating funding for pavement and bridge repair or improvement. The process and results described in this chapter demonstrate one way of incorporating freight value into the pavement and bridge preservation program.

7.1 Identifying High Priority Bridges

Figure 7.1 shows all Texas bridges mapped to the Texas Freight Network[21].

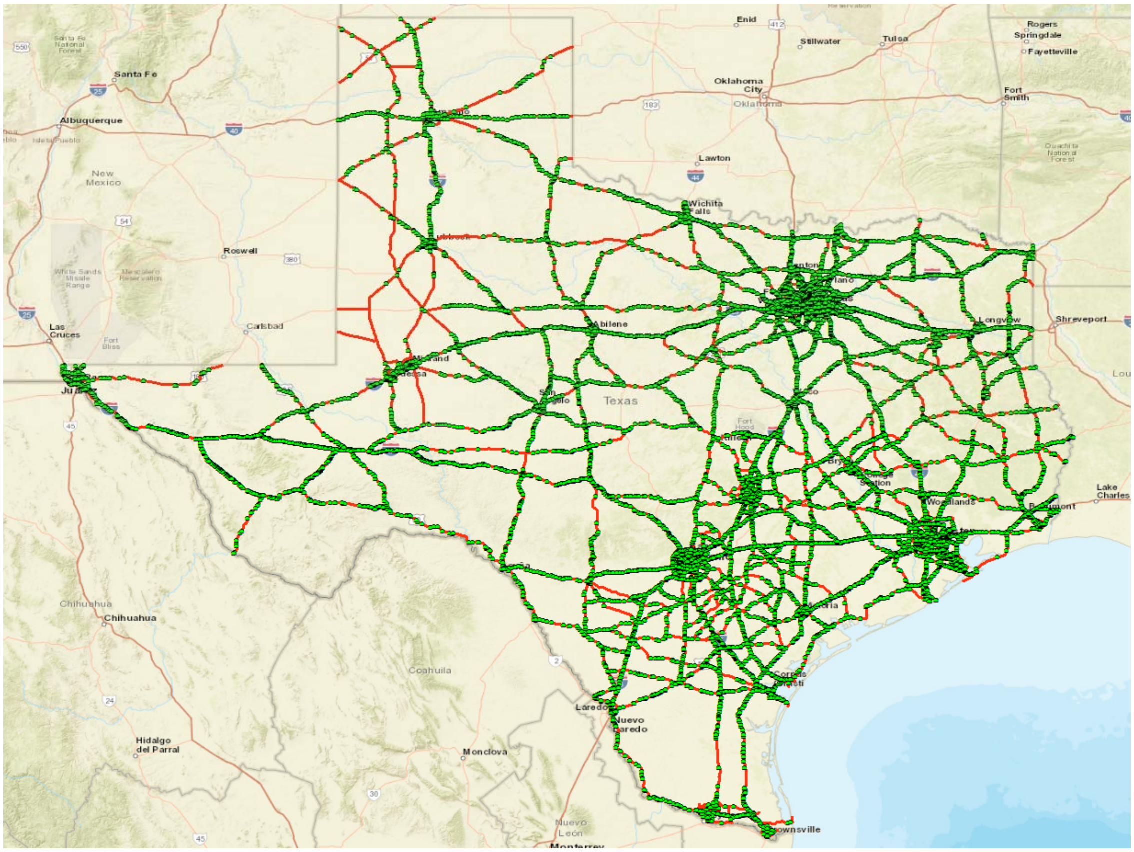


Figure 7.1: Bridges on Texas Primary and Secondary Freight Network

The bridge dataset was obtained from the National Bridge Inventory, which contains detailed information such as conditions, location, etc., for all the bridges in Texas. To use the commodity value estimation obtained in previous tasks to help prioritize bridge

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[21] Retrieved on August 2, 2016 from ArcGIS https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=b07d8609500c470eb1418543cb8dbcc2

improvement projects, a priority index was created based on the sufficiency rating of bridges and the value of commodities that are passing via the bridge. The value of commodities moving on the freight network varies widely, so log(value) was used to normalize the data.

$$bridge\ priority\ index\ = \frac{sufficiency\ rating}{log(value)} \tag{7.1}$$

The basic logic behind this priority index was that if a bridge has a low sufficiency rating but carries a high value of commodities, this bridge will merit a higher priority in terms of receiving funding for improvement. For all the bridges on the freight network, if sufficiency rating data and value data were available, the bridge priority index was calculated. Then, based on this index, those bridges were ranked. Figures 7.2 through 7.4 show the top 100, 500, and 1000 bridges selected based on this priority index.

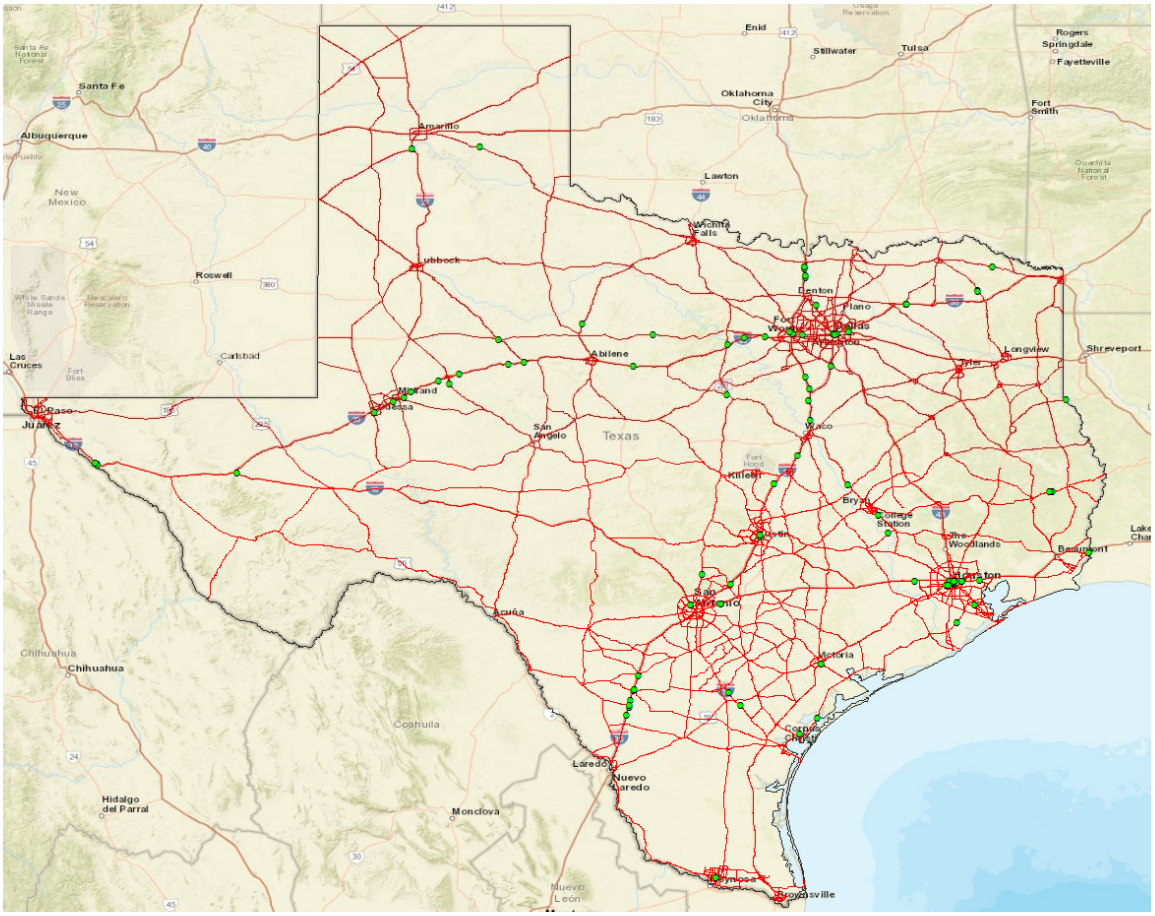

Figure 7.2: Top 100 Bridges on the Investment Priority List

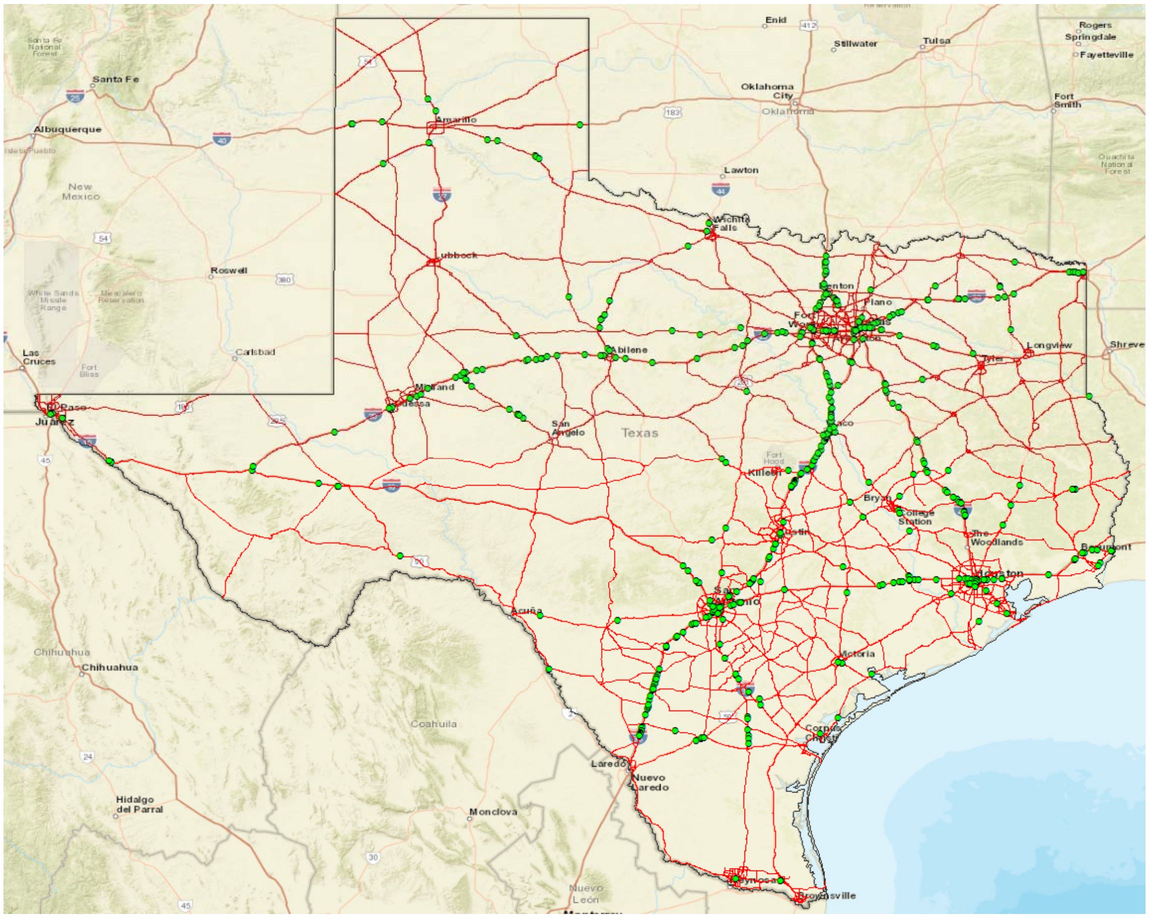

Figure 7.3: Top 500 Bridges on the Investment Priority List

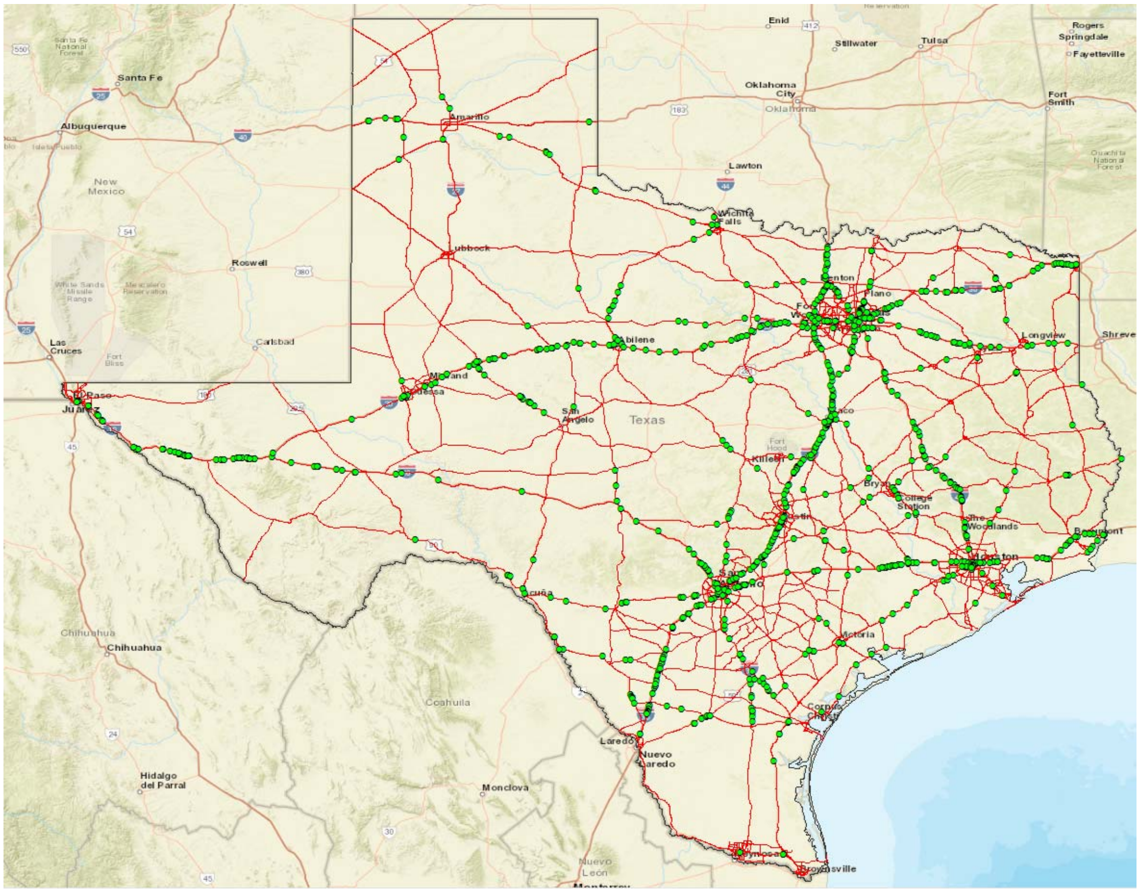

Figure 7.4: Top 1000 Bridges on the Investment Priority List

7.2 Identifying High Priority Pavement Sections

Similar to the bridges, pavement sections can also be ranked based on their conditions and the values of commodities moving on the roadway network. This was done by linking the value estimates to PMIS, the system that contains detailed information about pavement sections. Among those information types, condition score is an important measure to evaluate the overall condition of the pavement and was used in this study to create the priority index.

$$pavement\ priority\ index\ = \frac{condition\ score}{log(value)} \tag{7.2}$$

Similarly, if a pavement section has a lower condition score but carries higher commodity values, then this section will get higher priority in terms of receiving funding for improvement. Based on the calculated pavement priority index, the top 100, 500, and 1000 pavement sections were selected and are shown in Figure 7.5, 7.6, and 7.7 respectively.

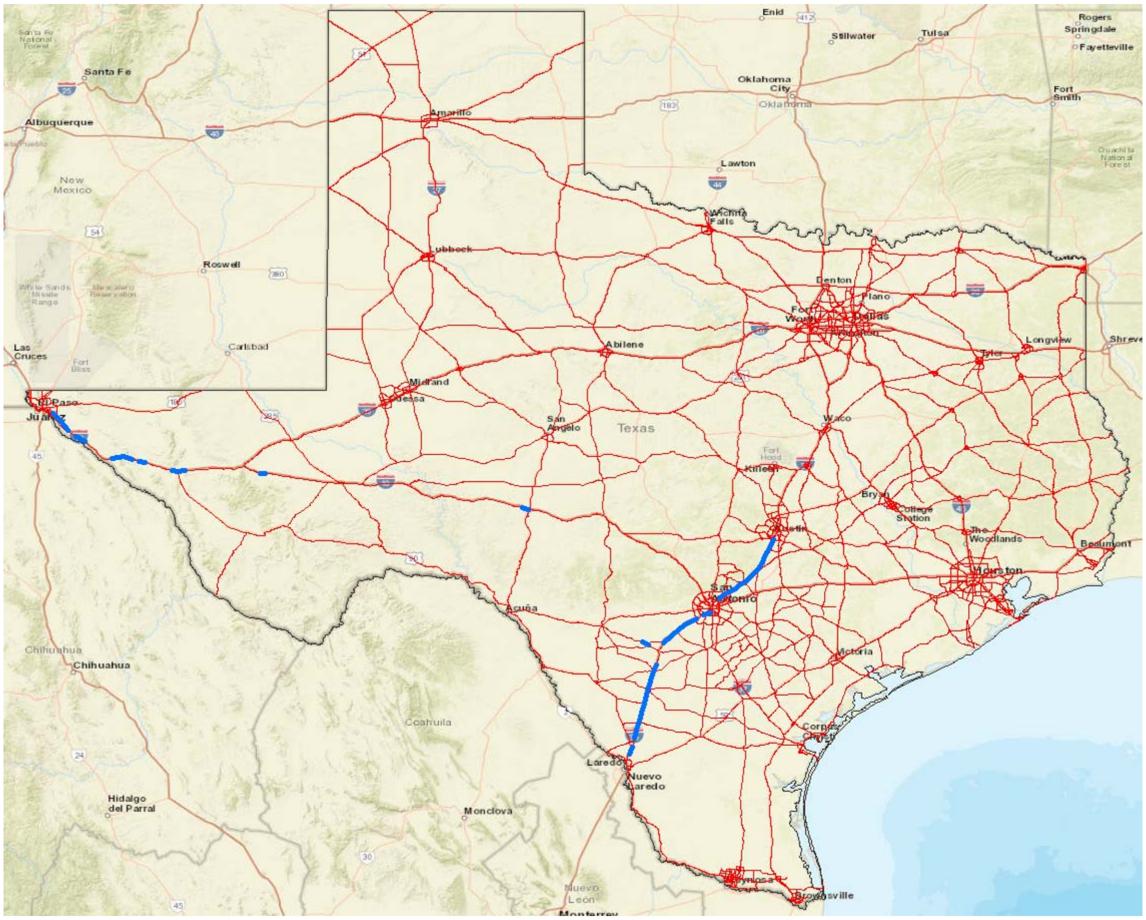

Figure 7.5: Top 100 Pavement Sections on the Investment Priority List

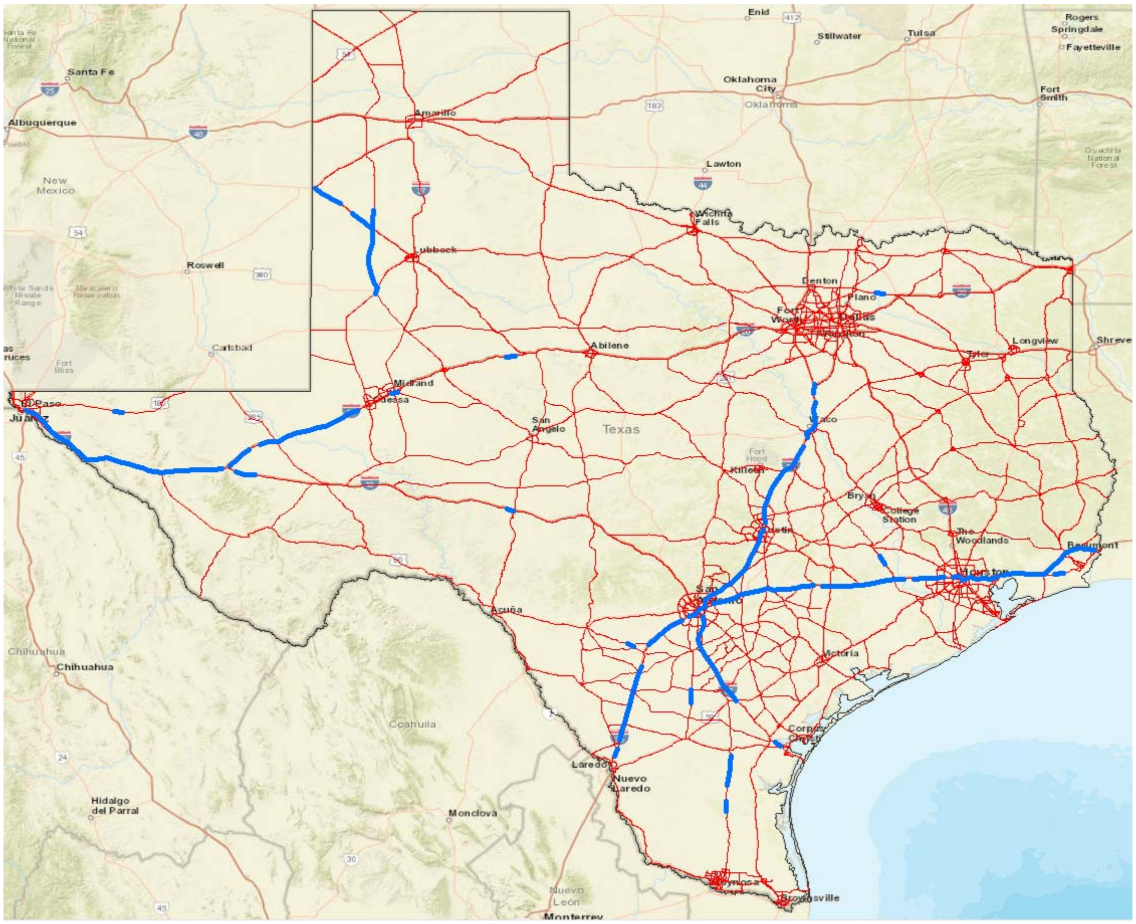

Figure 7.6: Top 500 Pavement Sections on the Investment Priority List

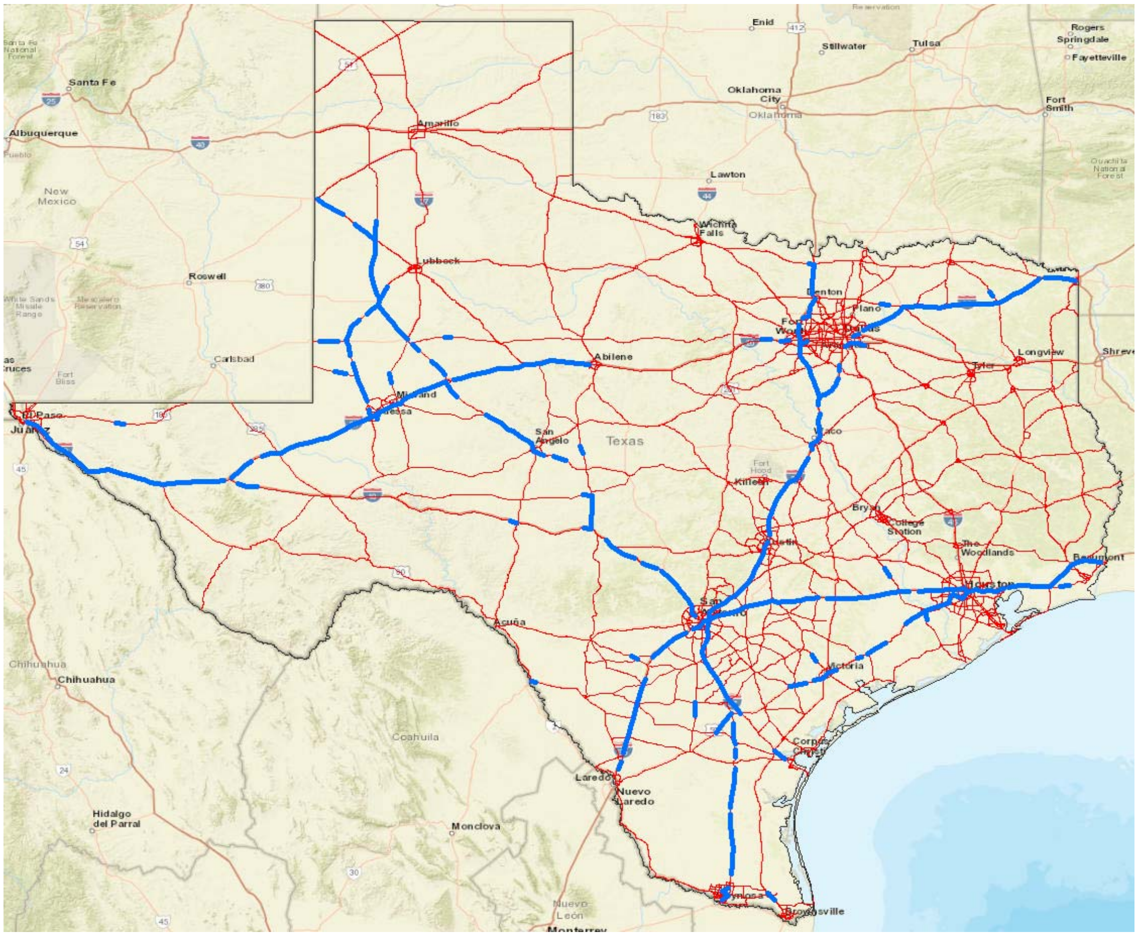

Figure 7.7: Top 1000 Pavement Sections on the Investment Priority List

The research team understands that more factors than just sufficiency rate/condition score and commodity values will be considered when infrastructure investment decisions are made in practice, but this chapter demonstrates how commodity value can be used to support this decision-making process and explored one way to do so.

Chapter 8. Summary and Conclusions

The purpose of this project was to address the growing need to account for the role of the freight network in supporting the economy. After an extensive literature review on commodity flow estimation methods, the research team pursued a commodity-specific modeling approach that can be used to estimate the flows of a particular commodity along a given network. The methodology is flexible enough to accept the wide range of data sources that will be encountered when analyzing a chosen commodity.

To refine the methodology, the project tested it with ten commodities from diverse industries. These commodities were selected based on a review of FAF4 search results for top-ranked commodities by value and weight, top-ranked agricultural commodities by cash receipts, and the commodities section of the Office of the Governor's key industry sectors. With concurrence from the sponsor, the final commodities tested were:

- Cattle
- Grain Sorghum and Corn
- Broilers
- Eggs
- Timber
- Gasoline and Fuel Ethanol
- Motor Vehicles
- Electronics
- Plastic and Rubber
- Sulfur and Sulfuric Acid

For each commodity, the flow estimation followed the procedure of finding commodity-specific data sources, creating county-to-county OD flows, performing network analysis, comparing results with existing databases, and incorporating the impact of seasonal variation and congestion.

Through online investigation and communication with industry representatives, the research team found data sources that could be used to estimate trip generation, trip attraction, trip distribution, transportation mode, and typical truck type for transportation for each commodity. For some commodities, the research team found rich datasets unique to the commodity that allowed for the creation of extensive county-to-county OD flows (or alternatively, an understanding that most flow stays within one county), whereas for some other commodities, datasets were difficult to find or incomplete, or the supply chain became too nebulous (i.e., too many uncertainties and assumptions associated with connecting facilities in the supply chain).

For commodities and supply chain sections for which rich data was available, the research team estimated county-to-county flow matrices using those found data sources. The specific approach of estimating production and attraction varied depending on the commodity under study, but they were usually estimated based on following types of data:

- County-level production data (e.g., some agricultural commodities)
- Production/consumption facility capacity, tax revenue, number of employees, etc.
- County population
- State-level production or consumption data disaggregated to a county level based on facility location, capacity, county population, etc.

Gravity models were then usually used to distribute estimated productions and attractions among different OD pairs with the exception of several commodities whose shipment from their origins to destinations were known from collected information (e.g., cattle). Estimated OD matrices were then converted into truck matrices and value matrices based on the typical truck type used and the prevailing market price of the commodity.

Link-level estimates of truck volume and commodity values were then obtained by assigning estimated truck matrices and value matrices to the roadway network. The network was developed based on the Texas primary and secondary freight network and SAM.

The research team evaluated the seasonal variation of commodities based on data related to those commodities' production and consumption. Following commodities were found have obvious seasonal variations:

- Cattle
- Corn (farms to elevators)
- Grain sorghum (farms to elevators)
- Corn and grain sorghum (elevators to feed yards)
- Gasoline
- Motor vehicles
- Electronics

The researchers found that commodities with significant seasonal variation can cause high truck volume during peak seasonal periods and those trucks' impact on infrastructure can be underestimated if only annual estimations are used.

The research team also explored ways of incorporating the impact of congestion into the modeling process. We used congested OD travel time as impedance in the gravity model for some commodities during the trip distribution step, and performed the user equilibrium traffic assignment based on congested link travel time during the network analysis step. By comparing the results obtained with and without considering the impact of congestion, we found that congestion can impact commodities' destination and route choices. However, a more thorough understanding of different stakeholders' decision-making processes is required to capture all of the factors that affect commodities' destination, route, and other logistic choices.

The modeling results were compared with TDMS data and Transearch data. However, due to different data structures and different scales of modeling subjects, it is impossible to make a direct one-to-one comparison between the modeling results with these two or any other existing databases. The comparison with TDMS data showed that the assignment results on most links were reasonable. Our model overestimates truck flows on a few links, primarily because the roadway network used is confined to the Texas primary and secondary freight network. The comparison between the modeling results with Transearch data demonstrated that when the Transearch commodity type matches well with the commodity modeled in this project (e.g., eggs and motor vehicles), the differences between two models fall within an acceptable range.

Based on the value estimates, the research team developed a scoring procedure as an example of how this information can inform freight network investment decisions. Because freight movements play such a vital role in the state and national economies, such a formulation could help improve shipping efficiency and increase productivity because traditional infrastructure investment decisions are usually made based on the condition of the infrastructure and the traffic volume without considering the value of commodities moved on the infrastructure.

The researchers found that the commodity-based approach can use commodity-specific data to develop a flow estimation methodology that is tailored for that commodity and therefore provides opportunity to perform detailed analysis of that commodity's movement along its supply chain. This study sought to understand the complexities of the interactions between the key stakeholders in freight movement. However, this commodity-specific approach requires detailed study of each commodity and can be both time- and resource-consuming if it is applied to all commodities. Therefore, this approach is more suitable for detailed logistic chain-based study of a small set of target commodities. More studies need to be performed to develop a methodology that can be used to estimate the total value of all commodities moved on the roadway at a more spatially disaggregated level (e.g., county-to-county) than exiting databases (e.g., FAF).

Based on this study, the research team recommends that commodity values be considered in the investment decision-making process so that those roadways carrying high values of freight can receive commensurate funding for improvements. It is also recommended that peak seasonal periods and daily truck volume during those periods should be identified so that the impact of those commodities' movements on infrastructure can be more accurately evaluated.

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