Third Edition

Quick Response Freight Methods

September 2019

U.S. Department of Transportation
Federal Highway Administration

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FOREWORD

The Federal Highway Administration (FHWA) Office of Operations (HOP) is pleased to present the third edition of the Quick Response Freight Methods (QRFM).

This report serves as a reference for transportation planners, departments of transportation, metropolitan planning organizations (MPOs) and other transportation agencies tasked with the development of freight forecasts. The QRFM provides an overview of the framework, methodology, and concepts of freight forecasting, as well as the history, definitions, and controlling factors behind freight movements. The QRFM also describes the existing data sources and data collection methods used to develop freight forecasts, presents a range of freight forecasting analysis methods in increasing order of complexity, and shares case studies that highlights how agencies address application issues in disparate geographies using a variety of methods and estimation data. We invite your comments and feedback, so we can continue to improve future editions of the QRFM.

There are two previous printings of this publication. This publication's status is: final.

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16. Abstract

Freight has a significant impact on the economy, on both the National and regional level. The transport of freight accounts for almost nine percent of the Gross Domestic Product in the U.S., which makes efficient freight and commercial truck travel essential to the country's economic well-being. The freight system moves 55 million tons of goods worth more than $49 billion each day, and this amount will increase. The Freight Analysis Framework (FAF) forecasts that between 2015 and 2045, the ton-miles of freight will grow by 60 percent overall and 75 percent on the highway system, while the population is only expected to grow by 22 percent according to U.S. Census forecasts.

Understanding and forecasting freight flow is a critical component for planning future transportation capacity, operation, preservation, safety, security, and energy and economic investment needs. Transportation investments are capital intensive and represent long-term financial commitments, making it critical that transportation planners possess both the tools and the skills to forecast freight demand and analyze scenarios and investment alternatives as part of the overall transportation analysis. This third update of Quick Response Freight Methods (QRFM) will prepare transportation planners to meet these needs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ACRONYMS

3D	Three Dimensional
AAR	American Association of Railroads
AASHTO	American Association of State Highway and Transportation Officials
ABM	Activity-Based Models
ADOT	Arizona Department of Transportation
AGF	Annual Growth Factor
AMPO	Association of Metropolitan Planning Organizations
APA	American Planning Association
AQ	Air Quality
ATL	Average Trip Length
ATRI	American Transportation Research Institute
BEA	Bureau of Economic Analysis
BEC	Broad Economic Categories
BLS	Bureau of Labor Statistics
BPR	Bureau of Public Road
BTS	Bureau of Transportation Statistics
Caltrans	California Department of Transportation
CBD	Central Business District
CBP	County Business Patterns
CES	Current Employment Statistics
CFMP	California Freight Mobility Plan
CFS	Commodity Flow Survey
CG	Commodity Groups
CMAQ	Congestion Mitigation and Air Quality
CMP	Congestion Management Process
CRFC	Critical Rural Freight Corridors
CSA	Combined Statistical Area
CSFFM	California Statewide Freight Forecasting Model
CSTDM	California Statewide Travel Demand Model
CTP	California Transportation Plan
CU	Combination Unit
CUFC	Critical Urban Freight Corridors
CV	Commercial Vehicle
CWS	Carload Waybill Sample

DC	Distribution Center
DMV	Department of Motor Vehicles
DOL	Department of Labor
DOT	Department of Transportation
DTA	Dynamic Traffic Assignment
EDR	Economic Development Research
EE	External-External
EI	External-Internal
EIA	Environmental Impact Analysis
EIS	Environmental Impact Statements
EPA	Environmental Protection Agency
FAF	Freight Analysis Framework
FAME	Freight Activity Microsimulation Estimator
FAST Act	Fixing America's Surface Transportation
FAZ	Freight Analysis Zones
FDOT	Florida Department of Transportation
FEU	Forty-Foot Equivalent Unit
FG	Freight Generation
FHWA	Federal Highway Administration
FLSWM	Florida Statewide Model
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTAP	Freight Transshipment Assignment Problem
FTG	Freight Trip Generation
GCD	Great Circle Distances
GIS	Geographic information system
GPS	Global positioning system
GSP	Gross State Product
GVW	Gross Vehicle Weight
GVWR	Gross Vehicle Weight Rating
HAZMAT	Hazardous Material
HCM	Highway Capacity Manual
HOV	High Occupancy Vehicle
HPMS	Highway Performance Monitoring System
HS	Harmonized System

IAP	Implementation and Technical Assistance Program
ICC	Interstate Commerce Commission
ID	Identification
IE	Internal-External
iFROM	Iowa Freight Optimization Model
iTRAM	Iowa Statewide Traffic Analysis Model
LAUS	Local Area Unemployment Statistics
LBS	Location Based Services
LEHD	Longitudinal Employer-Household Dynamics
LPOE	Land Port of Entry
LRTP	Long Range Transportation Plans
LTL	Less Than Truckload
LU	Land Use
MAG	Maricopa Association of Governments
MAP-21	Moving Ahead for Progress in the 21st Century
MC	Mode Choice
MFN	Multimodal Freight Network
MLC	Main Line Class
MMA	Multimodal Multiclass Assignment
MNL	Multinomial Logit
MPH	Miles Per Hour
MPO	Metropolitan Planning Organizations
MRI	Machine Readable Input
MS	Mode Share
MSA	Metropolitan Statistical Area
NAFTA	North American Free Trade Agreement
NAICS	North American Industry Classification System
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
n.e.c.	Not elsewhere classified
NETS	National Establishment Time Series
NHB	Non-Home-Based
NHFN	National Freight Highway Network
NHFP	National Highway Freight Program
NHPN	National Highway Planning Network

NHTSA	National Highway Traffic Safety Administration
NPMRDS	National Performance Management Research Data Set
NTAD	National Transportation Database
NTRC	National Transportation Research Center
NYBPM	New York Best Practice Model
NYMTC	New York Metropolitan Transportation Council
O-D	Origin-Destination
ODME	Origin-Destination Matrix Estimation
OES	Occupational Employment Statistics
OLS	Ordinary Least Squares
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
PAG	Pima Association of Governments
PC	Production-Consumption
PCE	Passenger Car Equivalent
PIERS	Port Import Export Reporting Service
PMS	Performance Monitoring System
POE	Port of Entry
PUMS	Public Use Microdata Sample
QA	Quality Assurance
QC	Quality Control
QRFM	Quick Response Freight Methods
RMV	Registries of Motor Vehicles
RTPA	Regional Transportation Planning Agencies
SCAG	Southern California Association of Governments
SCTG	Standard Classification of Transported Goods
SED	Socioeconomic Data
SEM	Structural Equation Modeling
SEMCOD	Structural Equations for Multi-Commodity O-D Distribution Model
SG	Service Generation
SHRP	Strategic Highway Research Program
SPBP	San Pedro Bay Ports
STA	Static Traffic Assignment
STB	Surface Transportation Board
STCC	Standard Transportation Commodity Classification

STG	Service-Trip Generation
STIC	Standard International Trade Classification
SU	Single Unit
SUV	Sport Utility Vehicle
SWM	Statewide Model
TAMS	Truck Activity Monitoring System
TAZ	Traffic Analysis Zone
TCU	Telematics Control Unit
TD	Trip Distribution
TEU	Twenty-Foot Equivalent Unit
TG	Trip Generation
TIA	Traffic Impact Analysis
TIP	Transportation Improvement Program
TIUS	Truck Inventory and Use Survey
TLN	Transport Logistics Nodes
TMAS	Travel Monitoring Analysis System
TMG	Traffic Monitoring Guide
TMIP	Travel Model Improvement Program
TnDOT	Tennessee Department of Transportation
TOD	Time of Day
TTTR	Truck Travel Time Reliability
TVT	Traffic Volume Trends
UCR	Urban Congestion Report
UPS	United Parcel Service
USACE	United States Army Corps of Engineers
USDOT	United States Department of Transportation
VDF	Volume-Delay Functions
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle Miles Traveled
VTRIS	Vehicle Travel Information System
WIM	Weigh-in-Motion

PART A. INTRODUCTION

The first three chapters of the *Quick Response Freight Methods, Third Edition* (QRFM) introduce *the framework, methodology, and concepts discussed in this revision*. Chapter 1 introduces this edition of the QRFM. Chapter 2 discusses the concepts included in this third edition. Chapter 3 discusses the framework of freight forecasting, focusing on which data can be varied in freight forecasting.

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CHAPTER 1. INTRODUCTION

Freight has a significant impact on the economy, on both the National and regional level. The transport of freight accounts for almost nine percent of the Gross Domestic Product (GDP) in the U.S., which makes efficient freight and commercial truck travel essential to the country's economic well-being. The freight system moves 55 million tons of goods worth more than $49 billion each day, and this amount will increase. The Freight Analysis Framework (FAF) forecasts that between 2015 and 2045, the ton-miles of freight will grow by 60 percent overall and 75 percent on the highway system, while the population is only expected to grow by 22 percent according to U.S. Census forecasts.

The freight system is made up of a vast, complex network of almost seven million miles of highways, local roads, railways, navigable waterways, and pipelines. For the economy to grow, the freight system must be able to accommodate the projected growth without stress or bottlenecking; this requires effective transportation infrastructure planning on the national, State, and local level.

Understanding and forecasting freight flow is a critical component for planning future transportation capacity, operation, preservation, safety, security, and energy and economic investment needs. Transportation investments are capital intensive and represent long-term financial commitments, making it critical that transportation planners possess both the tools and the skills to forecast freight demand and analyze scenarios and investment alternatives as part of the overall transportation analysis. This third update of *Quick Response Freight Methods* (QRFM) will prepare transportation planners to meet these needs.

OBJECTIVES OF THE QUICK RESPONSE FREIGHT METHODS

While the acronym of this document remains QRFM, the title itself has changed. In previous editions, the "M" stood for "Manual," but it has been updated to better reflect the intent of this document; the "M" now stands for "Methods." The QRFM is an informational and descriptive resource, not a prescriptive manual outlining the mandatory practices to follow in freight planning. This document provides insight into the methods, data, and practices that are useful in conducting freight planning, analysis, and modeling. The revised title better conveys this emphasis.

The QRFM addresses the needs of a broad audience of transportation planners, helping them understand options that use various data sources and analysis methods to prepare freight demand and performance forecasts.

The objectives of the QRFM are to provide:

- Background information on the freight transportation system and factors that affect freight demand.
- The locations of available data and freight-related forecasts compiled by others and an understanding of how these data were applied to develop forecasts for specific facilities.

- Simple techniques and transferable parameters used to develop freight trip tables, allowing users to incorporate them with other trip tables developed through conventional planning and modeling processes.
- Site planning techniques and transferable parameters for new facilities such as regional warehouses, truck terminals, and intermodal facilities, as part of Traffic Impact Analysis (TIAs) and Environmental Impact Assessment (EIA)/Environmental Impact Statements (EIS).

This document covers freight issues at different levels of analysis. For site planning, the QRFM includes methods for forecasting the demand and performance of freight truck trips to and from specific locations or on specific routes. For general planning purposes, the methods shown in the examples include procedures to prepare analysis and data to support the development of State freight plans as required by Federal law and freight elements from general transportation planning documents prepared for other planning agencies. This includes preparing demand and performance forecasts used in planning documents to evaluate freight program policies and projects.

The methods presented in the QRFM place a special emphasis on readily available data and reference parameters, making these methods easier to implement. The document provides information on which parameters are suitable for transfer and which are specific to the economy of a study area that can be adapted using data specially collected for that study area.

The QRFM discusses emerging analytical methodologies and data collection techniques that can improve the accuracy and utility of freight analysis and planning processes.

FREIGHT PLANNING AND POLICY PROVISIONS, REGULATIONS, AND GUIDANCE

The Federal laws governing transportation planning (23 U.S.C. 133 and 23 U.S.C. 134) and transit planning (49 U.S.C. 5303 and 49 U.S.C. 5304) require States and metropolitan planning organizations (MPOs) to consider freight in their long-range plans, transportation improvement programs, and annual work programs. These requirements were strengthened by the Federal Highway Authorization legislation: Moving Ahead for Progress in the 21st Century (MAP-21) enacted in 2012 and the Fixing America's Surface Transportation Act (FAST Act) enacted in 2015. There are still some issues that need to be addressed before the States, MPOs, and other planning agencies can be effective in freight planning:

- Transportation agencies have more experience planning the movement of passengers than the movement of freight.
- Current and historical data on freight, especially truck movements, are extremely limited (although access to data on system performance [e.g., operating speeds] has improved significantly).

These are the same issues cited in the previous edition of the QRFM published in 2007, and they remain important today. While transportation agencies are beginning to emphasize freight transportation performance, passenger movement remains their top priority. Most freight planning models and methods involve both operational and planning issues that require data and information that are unavailable to most planning agencies.

The FAST Act established a new National Highway Freight Program (NHFP) to improve the efficient movement of freight, and it includes a provision that requires each State to develop a State Freight Plan to receive funding under NHFP 23 U.S.C. 167. The plan provides a comprehensive freight plan framework for immediate and long-range planning activities and State investments that meets all of the requirements to receive funding [Pub. L. No. 114-94, § 8001 (codified at 49 U.S.C. 70202)].

The U.S. Department of Transportation (DOT) has also established a National Freight Highway Network (NHFN), documented at https://ops.fhwa.dot.gov/freight/infrastructure/nfn/index.htm. States can identify Critical Rural Freight Corridors (CRFC) for inclusion in the NHFN, and MPOs, in cooperation with States, can identify Critical Urban Freight Corridors (CUFC) for inclusion in the NHFN.

To qualify for NHFP funds, each State must develop a freight plan that comprehensively addresses freight planning activities and investments; this includes the identification, ranking, and prioritization of bottlenecks. There is a financial incentive for preparing these freight plans and programs, and the NHFP encourages States and MPOs to form freight advisory councils that will assist them in these efforts.

MAP-21 set seven national goals for a performance-based transportation program, including a goal for freight movement and economic vitality to improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development. As part of the performance-based approach, performance measures were set for the national goals. The freight performance measure is Truck Travel Time Reliability (TTTR) on the Interstate system, and MAP-21 requires States and MPOs to set performance targets for TTTR and measure their progress. Resources on TTTR and related topics are available at https://ops.fhwa.dot.gov/freight/pol_plng_finance/policy/ and https://ops.fhwa.dot.gov/freight/freight_analysis/fdmdi/index.htm.

These sources only speak to the national perspective on policies, guidelines, and regulations; there are likely other State and local regulations that are not included in this document. This guide recommends that practitioners seek guidance from their own States and MPOs and national public agency advisory groups such as the American Association of State Highway and Transportation Officials (AASHTO), the Association of Metropolitan Planning Organizations (AMPO), and the American Planning Association (APA) for State and local laws and regulations.

OUTLINE OF THE QUICK RESPONSE FREIGHT METHODS

The QRFM is organized in four parts, with each part divided into chapters. Each chapter is independent of the others, and the user may read the chapters that best serve their interests. This update to the QRFM includes the following components:

Part A introduces the material, including this chapter, and:

- **Chapter 2: Freight Forecasting: History and Definitions—**This chapter describes the history of freight/truck modeling, the general concept and definitions used in truck/freight planning, the multimodal commodity and truck vehicle classification systems, and the similarities between passenger and freight modeling terms.

- **Chapter 3: Freight and Commercial Vehicles: Controlling Factors—**This chapter demonstrates how understanding the underlying factors that control the observed freight and goods movements can help planners identify issues that they need to address in forecasting. The factors include:

  - **Economic Structure—**The economic, industrial, and commodity-related factors that give rise to the demand for freight and help identify who are the actors who move freight.
  - **Supply Chains and Logistics—**The factors that determine the spatial relationships, shipment sizes, frequency and other considerations that govern shipments.
  - **Cost and Service by Mode—**The modal factors that determine the costs and service levels by truck, rail, water, and air[1] freight modes reflect how freight moves.
  - **Freight Flows—**The network volumes quantify the freight movements inside vehicles on each freight modal network and reflect what and how much freight is moved.
  - **Organization and Public Policy—**This factor reflects the public policy that sets the rules and regulations that govern why and who freight movements are the way they are.

Part B consists of chapters that discuss the various data sources that are available to support freight forecasting:

- **Chapter 4: Existing Data—**This chapter describes the availability and content of different data sources and the advantages and disadvantages of using existing freight data, with attention to how these data can be used in Part C to support freight forecasting methods. The data discussed include:

  - Existing freight data such as commodity flow origin-destination (O-D) tables and freight truck volume estimates from the Freight Analysis Framework (FAF), the Commodity Flow Survey (CFS), and TRANSEARCH.
  - Existing freight infrastructure data such as the intermodal freight terminals provided by the National Transportation Atlas Database (NTAD), the transportation networks provided by the Oak Ridge National Laboratory's (ORNL) Center for Transportation Analysis, and the FAF.
  - Employment/industry data such as County Business Patterns (CBP), State employment data, longitudinal employer-household dynamics (LEHD) data, and InfoUSA.
  - Vehicle data such as the vehicle inventory usage survey (VIUS) and weigh-in-motion (WIM) data.
  - Modal usage data such as the railroad Carload Waybill Sample and the marine Waterborne Commerce.
  - Network performance data such as the Traffic Monitoring Analysis System, including

[1] Large flows of freight are also carried by pipelines. Pipelines are not addressed in this report because the commodities carried, generally petroleum and other liquid products, are specialized and unique to pipelines. Data on the distribution network and flows are not readily available and the flow of goods by pipeline rarely is addressed by the transportation audience for whom this report is intended.

the automatic traffic recorder data, vehicle classifications counts, and the National Performance Research Dataset.

- **Chapter 5: Local Data Collection—**This chapter discusses new data sources that can be used to supplement methods described in Part C. Topics include data collection issues such as sample sizes and implementation issues for various types of supporting data collection. The chapter outlines various types of new data collection methods such as establishment surveys, diaries, intercept surveys, and new truck or other freight vehicle counts. In addition, the discussion includes methods to collect information about freight infrastructure, such as field inspections of freight facilities, line-haul, and terminals, and how new emerging data analysis techniques, such as "Big Data" processing, can support and supplement these efforts.

Part C consists of freight forecasting methods, including simple factoring methods, methods that incorporate freight forecasting in traditional transportation modeling in urban, State, and site settings, and commodity flow methods that use multimodal freight demand data to create freight forecasts:

- **Chapter 6: Analysis of Existing Data and Forecasts—**This chapter analyzes existing data and forecasts to describe existing and potential freight demands, bottlenecks, and needs that are used to prepare and support freight plans.

- **Chapter 7: Growth Factor Methods—T**his chapter describes how growth factor methods can be used for forecasting freight demand using historic trends and linear and nonlinear regressions based on single and multiple independent variables.

- **Chapter 8: Commodity Modeling—**This chapter discusses how a table of goods movements, defined by commodity, can be used in freight forecasting. Issues include how to obtain commodity flow tables, geographic issues related to these tables, and methods for disaggregating or factoring commodity flows.

- **Chapter 9: Trip Based Forecasting—**This chapter addresses how planners use the traditional "four-step" transportation forecasting process (Trip Generation, Trip Distribution, Mode Split/Conversion to Vehicle Flows, and Network Assignment) to forecast goods movements in traditional urban transportation planning models, State transportation planning models, and site planning. The methods discussed consider the different definitions of freight transportation discussed in chapter 2. While it does not fall strictly under freight planning, this chapter discusses the analysis of trucks that serve both freight and non-freight purposes.

- **Chapter 10: Supply Chain/Tour-based Forecasting—**This chapter reviews the new and emerging techniques that address the combination of freight/truck trips into tours, typically called supply chains in freight analysis. These methods are comparable to activity-based models that are used in passenger forecasting.

- **Chapter 11: Model Calibration and Validation—**This chapter discusses the special considerations used to validate freight models, especially those with transferred parameters. The discussion includes calibrating freight models and forecasts to reflect how well models correspond to existing conditions and validating freight models to reflect how well models correspond to expected changes. This chapter considers the sources of validation and calibration data for freight forecasting and identifies the steps of freight models that can be adjusted to improve calibration and validation.

Part D describes the possible applications of freight forecasting methods:

- **Chapter 12: Application Challenges—**This chapter discusses the importance of freight forecasts to transportation planning, the development of alternative methods, and the implementation of forecasts in the transportation planning process.

- **Chapter 13: Case Studies—**This chapter presents actual case studies of how organizations addressed methodological and data issues; they are organized to highlight different methods and data collection techniques. The case studies come from three State departments of transportation and three MPOs, including:

    - The California Statewide freight forecasting model.
    - The Florida Department of Transportation’s FreightSim model.
    - Iowa’s Statewide traffic analysis and freight optimization model.
    - The Maricopa Association of Governments model.
    - The New York Metropolitan Council’s best practices model.
    - The Memphis Metropolitan Planning Organization truck model.

CHAPTER 2. FREIGHT FORECASTING: HISTORY AND DEFINITIONS

This section of the *Quick Response Freight Methods* (QRFM) update provides a detailed discussion of the controlling factors that impact freight demand analysis and forecasting. These factors can be broadly grouped into the following categories:

- **Economic Structure—**Who moves freight?
- **Supply Chains and Logistics—**Where does freight move?
- **Cost and Service by Mode—**How does freight move?
- **Freight Flows—**What and how much freight is moved?
- **Organization and Public Policy—**Why does freight move the way it does?

GENERAL CONCEPTS

Freight travel demand models forecast the usage and system performance implications of freight travel behavior associated with socioeconomic activity. In these models, freight usage is the measurement of the volumes of trucks and tonnages of commodities transported, while freight performance is the measurement of the times and costs of transporting the freight.

Modelers use socioeconomic forecasts as inputs to forecast freight demand and performance. They need to obtain growth, investment, and employment forecasts across economic sectors that use facilities that serve passenger and freight travel flows, such as ports or rail terminals. While trucks transport freight, not all freight is transported by truck; rail, water, air, and pipelines serve important roles in freight transport.

Similarly, the terms "freight truck" and "truck" are often used interchangeably, but there are important distinctions. While trucks transport a significant amount of freight, trucks also transport goods that are not considered freight, such as transporting internal goods within a firm from one location to another or carrying tools that are used to provide services. These other uses may not be included in the data used to develop freight models. For example, the loaded network that accompanies Freight Analysis Framework version 4 (FAF4) indicates that only 50 percent of the truck vehicle miles traveled (VMT) on the FAF highway network in 2012 were traveled by freight trucks.

The largest category of non-freight trucks are service vehicles: trucks that carry tools and materials to provide services such as electricians and plumbers. Even trucks delivering goods are not always freight trucks; the freight truck category only includes cargo transported by a common carrier for a fee, which excludes cargo transported for local delivery or by private fleets (e.g., UPS, FedEx, and Walmart). The estimation data used to develop freight models does not classify the local delivery of cargo as freight, which will be discussed in later chapters.[2]

Forecasters often estimate freight commodity flows by tonnage, not trucks; the conversion of freight tons to trucks captures those trucks while they are loaded, but not while traveling empty. These loaded and empty trucks represent a substantial amount of traffic on the roadways, making them important to include in roadway planning projects such as congestion analyses or pavement

[2] TRANSEARCH, the Freight Analysis Framework (FAF) and the Commodity Flow Survey (CFS) are examples of these data and are described in greater detail in chapter 4.

impacts assessments. Figure 1 is a Venn diagram showing the relationship between freight movements and truck activity. Trucks traveling in urban areas are defined as a subset of all trucks traveling in both urban and rural areas; this is an important distinction because commodity flow data sources often underreport short haul freight movements within an urban area.

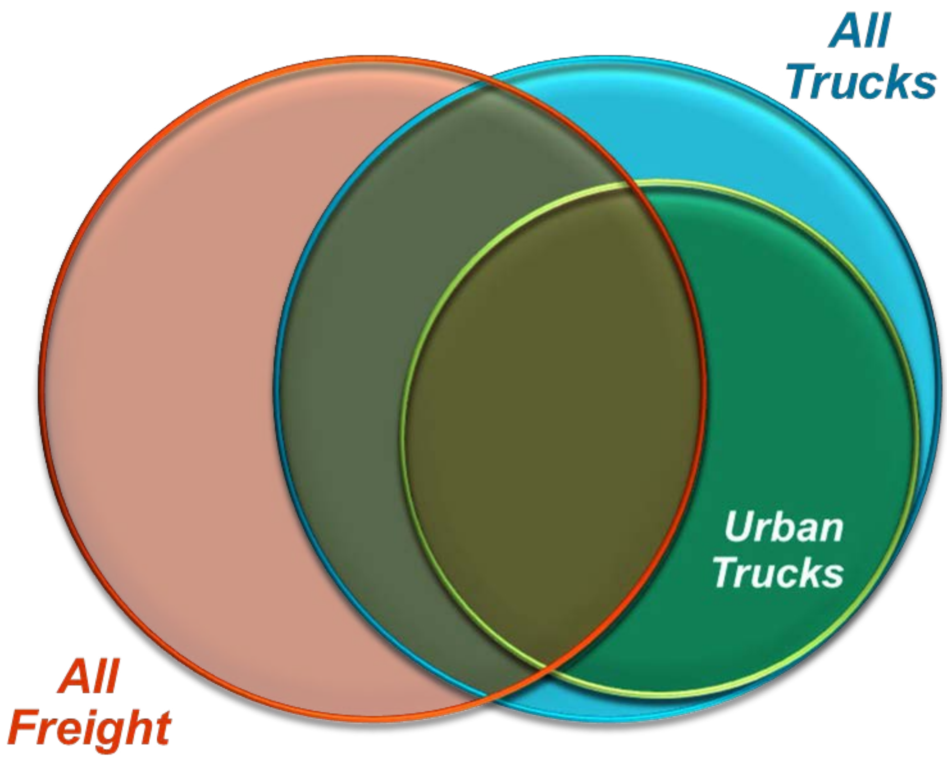

Figure 1. Venn diagram. Freight (all modes) versus trucks (all purposes).
(Source: Federal Highway Administration.)

While the *Quick Response Freight Methods* (QRFM) emphasizes freight usage and performance, planners also need to forecast the demand and performance of other vehicles that share networks with freight. In many instances, highway travel includes freight trucks, non-freight trucks, and passenger vehicles that share the same roads. Freight truck travel times on highways reflect the congestion times resulting from those other demands. Unless planners include the usage and performance of these other components of travel, it may not be possible to forecast freight demand and performance. Because most passenger forecasts do not include non-freight trucks, the QRFM will account for their usage.

PROGRESSION OF TRUCK/FREIGHT MODELING

Truck/freight modeling methods have changed over time, evolving from simple factoring to more advanced techniques. As methods become more complex, the need for detailed and quality data has increased.

Figure 2 shows the evolution of freight modeling, starting with simple factoring of existing auto trips and moving to the development of truck trip generation rates and the use of matrix estimation techniques to account for observed truck traffic. Figure 2 also shows more sophisticated and recent methods, including the analysis of freight flows by commodity, the analysis of entire truck tours instead of individual truck trips, and the more nuanced understanding of supply chain models that underlies the observed freight flows by one or more freight modes.

Factored Auto Tables

Some early truck models created truck trip tables by factoring a passenger auto table, which generates a truck trip table with origins and destinations that can be assigned to a network separately from the auto traffic. Although this truck trip table could be subject to truck assignment rules such as truck road prohibitions, it retains the underlying pattern of auto trips, an assumption that is not realistic in most analytical contexts.

Truck Generation Rates (Formerly Urban Truck Rates)

To develop a truck trip table that reflects truck travel patterns and the underlying freight behavior, planners conducted commercial vehicle surveys to provide estimation data for truck generation and distribution models. Truck generation rates developed for Phoenix served as the basis for the equations published in the 1996 edition of the Federal Highway Administration's (FHWA) *Quick Response Freight Manual* (QRFM I). With those models, planners could develop trip equations for different sizes of trucks (e.g., four-tire pickups, single-unit trucks, and combination-unit trucks) and different truck activities (e.g., manufacturing, service, retail, and households). To validate truck counts, planners typically combined those vehicle types, since truck counts only report truck traffic by truck classification or size, which do not match up well.

Origin Destination Matrix Estimation

Jurisdictions that were not comfortable using the 1996 version of the QRFM truck trip generation rates but could not undertake their own surveys developed truck trip tables through an Origin Destination Matrix Estimation (ODME) process that uses truck counts on links. Because those roadway truck counts could only differentiate by truck size and not by purpose, these ODME truck tables could not differentiate purpose or commodity. The ODME tables also varied depending on the seed/input table, which was often a QRFM-derived table aggregated by activity purposes to truck sizes.

Figure 2. Diagram. Progression and complexity of freight/truck models.
(Source: Federal Highway Administration.)

Commodity (Freight) Flows

Freight is the transport of goods by a common carrier for a fee, and most freight cargo in the U.S. is transported by truck. According to the Bureau of Transportation's Freight Facts and Figures for 2017, trucks transported approximately 72 percent of the tonnage reported in the FAF4, excluding the tonnage transported by pipelines. The databases used to estimate freight models do not necessarily include all cargo movements; for example, freight databases typically do not segregate the urban delivery of cargo, so planners must include them in "non-freight" truck models.

"Non-freight" purposes also include service, maintenance, and construction trucks. These trucks are not always defined as "non-freight" and some models collectively call them "service" trucks. Chapter 8 explores cases where models only assign a commodity table, and chapter 9 details cases where planners use reported freight and "non-freight" truck data to estimate trip-based models.

Truck Touring Models

Planners often use truck touring models to measure an average day at a scale appropriate for trips within a metropolitan area. A truck tour model can provide outputs to segment trips by different time of day (TOD) periods. The travel times associated with truck trips and the duration of time spent at stops between trips may affect the TOD for specific trips. In addition, trip distribution patterns of a tour are important because the destination of a trip on a tour becomes the origin of the next trip on a tour. These tour patterns may differ from those estimated by traditional trip distribution models that estimate trips between freight origins and destinations, omitting intermediary freight behavior where goods are picked up or moved through freight hubs.

Truck touring models share similarities with passenger activity-based models (ABM) that link passenger trips to provide a consistent treatment of the modes used throughout the tour. For example, a tour that goes from home to daycare to work to daycare to home might use an auto for the entire tour if an auto is required for the first trip of the day. Planners use ABMs to prevent unreasonable mode choices; though logical for an individual trip, the mode choice would not be logical for all the trips on a tour. For example, travelers who ride transit for their home to work trip are unlikely to drive their own car for the return trip of their tour from work to home.

The estimation data used in truck touring models seldom contain information on the commodity of the cargo. Even when the data includes this information, there is no guarantee that the cargo trip would be considered freight in a conventional freight database. Truck touring models seldom include freight commodity purposes and may not differentiate between freight and non-freight trucks. Chapter 10 discusses the development of truck touring for non-freight trucks.

Supply Chain Models

Supply chain models measure freight movement by all modes, not just by truck. A supply chain might include the rail shipment of cargo to a rail terminal followed by a truck trip to deliver the cargo to its destination. The shipper determines the supply chain based on the utility of each modal link in the supply chain and the handling utilities (e.g., time and cost) at the transfer points between modes along the supply chain (often called transport logistics nodes).

The nature of the transported cargo generally stays the same throughout the entirety of the supply chain, and shippers could consider certain attributes of the freight cargo (e.g., shipment size or shipment frequency) when choosing a specific supply chain. The origin of the cargo is the shipper of the freight and the destination of the cargo is the receiver of the freight. This approach differs from trip-based truck models that maintain a single mode for the freight and treat the transfer between modes as the origin of a new trip, typically as a special generator.

A supply chain model links these inter-connected trips. Like truck touring models, supply chain models link many individual freight trips, but they differ from truck touring models since supply chain tours can include all modes. Chapter 10 describes these supply chains (linked trips) and their use in freight forecasting in greater detail.

The progression from simpler approaches to more nuanced and data intensive methods of freight forecasting has not been adopted by all transportation planning agencies. While data availability and the understanding of freight forecasting methods have improved over time, the data collected and the forecasting applications used by any given agency depends on the resources available and the complexity of the freight problems addressed.

GENERAL DEFINITIONS

Freight analysis includes terminology that may be new to transportation practitioners. Glossaries of terms and acronyms are comprehensive and publicly accessible, most notably in https://ops.fhwa.dot.gov/freight/fpd/glossary/index.htm. This edition of the QRFM does not duplicate those efforts. However, there are additional definitions needed to better appreciate the data and methods described in this QRFM. The remainder of this chapter discusses:

- The types of freight forecasts addressed in the QRFM.
- The definition of commodities, the notion of multimodal and intermodal, and how origins-destinations, supply chains, and agents affect the choices and performance of freight.
- Freight commodity classification systems and their level of detail.
- Truck classification systems based on weight, number of axles, and type of vehicle.
- Commonalities in the passenger and freight approaches to forecasting.

FORECASTING IN THE QUICK RESPONSE FREIGHT METHODS

There are two types of forecasts discussed in this edition of the QRFM:

- Flows to and from locations.
- Flows on network links between those locations.

The location can be a geographic area that might be a specific facility (e.g., a port), a geographic location (e.g., an analysis zone), or an aggregation of geographic locations (e.g., a county). The first type of flow is typically expressed as a trip table; the second type of flow reflects volumes that result from the "assignment" of that trip table of freight demand to the modal network.

The flow unit in the trip table is typically a multimodal unit because the mode might not yet be selected. The time of the trip table may not be consistent with the time period used in the network (e.g., annual versus average daily). Planners may need to convert the flow unit in the table assigned to a modal network from a general term (e.g., tons) to a modal specific term (e.g., trucks) using some commodity specific factor that relates them (e.g., payload factors/tons per truck by commodity).

PERFORMANCE IN THE QUICK RESPONSE FREIGHT METHODS

The performance of freight is typically reported and forecast for those attributes that are important in making choices among freight destinations, freight modes, or routes within freight models. The attributes that have been found to be important are travel time, speed, cost and reliability. Cost and reliability are often dependent on the travel times, schedules and/or and congestion on modal routes.

Commodities

Organizations transport different goods based on the transportation system available to them. Goods are grouped into commodities that have similar characteristics. Several organizations have developed commodity classifications, and their approaches better reflect their own uses and do not reflect the needs of analysts developing freight forecasts. The next section of this chapter discusses the different commodity classification systems. Each system has its own level of detail, which may not help planners group commodities by their expected behavior for freight forecasting purposes. Most applications of the QRFM typically use one to two dozen groupings of commodities.

Multimodal versus Intermodal

Multimodal, also known as "co-modal" and "synchro-modal," typically refers to a tour (a grouping of trips by shipment) where more than one mode of transportation will be used in one or more individual trips of the tour. The QRFM uses multimodal to describe this type of tour; co-modal and synchro-modal are more commonly used outside the U.S. or in operational (non-planning) applications.

Intermodal refers to the connection between different modes. While this is consistent with the concept of multimodal, the terms intermodal connector and intermodal terminal already have specific meanings in Federal transportation law with specific requirements. Intermodal, as used by railroads, refers to a type of service with specialized schedules and equipment that transports sealed shipping containers by rail.

Terminals where connections are made between modes are called transport logistic nodes (TLNs) to avoid confusion with the legal usage of intermodal terminals.

Linked Origins and Destinations

The QRFM defines a trip as the transport of goods traveling from one location to another by a single mode. Trips may require stops at intermediate terminals where the goods transfer from one mode to another. These stops are often treated as "special generators" because there is no apparent relationship between the economic sector producing the goods and the economic sector consuming the goods. While the trips are always reported, the connection between these trips at transfer points may not be reported. For example, some freight trips may be linked at these transfer points, but the shipper does not provide reporting that could be used to link these trips.

Supply Chains

There are different definitions of supply chains in the literature that range from the original concept of moving a commodity from the producer to the consumer using several steps to the practical consideration of supply chains in transportation that are the subject of the QRFM.

A supply chain is characterized by the attribute that is held constant over all shipments. An industry supply chain refers to the industry that is receiving raw materials from generic locations and is shipping finished products to generic locations. A firm supply chain refers to a specific firm that is receiving raw material from specific locations and is shipping finished products to specific locations.

However, these are not the typical uses of the term supply chain in the QRFM. A supply chain in the QRFM holds the commodity constant over the shipment even if the shipping industry or the firms are not held constant.

Given the available data on freight movements and the industry's current best practices in freight modeling, supply chains reflect goods movements between establishments starting with the producer of a commodity and ending with the retailer who represents the end of the supply chain. As freight modeling approaches evolve, future freight models may consider extending the supply chain to account for home delivery of the purchased product.

Supply Chain and Non-Freight Truck Tours

Tours consist of a grouping of connected and linked trips. Tours are present in a supply chain and are also present in travel by non-freight trucks. Freight supply chains represent tours that are made by vehicles that only carry cargo.

However, there are cases where the vehicle does not carry freight, but it may still operate within a tour of connected trips. Non-truck freight commodity modes, such as rail, carry only freight. Non-freight trucks may be linked, resulting in non-freight truck tours.

As noted above, supply chains reflect tours where the commodity remains the same but may include trips that are made with different modes. The tour formation considers the attributes of the trips and the attributes between trips, including the duration of time for handling at the end of one trip prior to the start of the next trip, which is the next leg of the tour.

Non-freight truck tours represent a group of trips by the same truck where the truck does not carry commodity freight.

Agents Making Choices in Goods Transport

In passenger modeling, the same traveler (e.g., an auto driver) makes most of the decisions in a trip that is included in a trip table and the assignment of the trips from that table on a network. In freight modeling, there are different agents making choices in the formation of the trip table (i.e., the shipper and receiver) and routing choices in the assignment of that trip (i.e., the operators of the modal vehicles carrying goods). This difference impacts the methods a planner uses to address the complexity of freight modeling.

FREIGHT COMMODITY CLASSIFICATION SYSTEMS

There are many commodity classification systems used to categorize freight, including the:

- Standard Transportation Commodity Classification (STCC).
- Standard Classification of Transported Goods (SCTG).
- Harmonized system (HS).
- Performance monitoring system (PMS).

Organizations use commodity classifications because certain characteristics of a commodity can affect the choice of mode in different scenarios; for example, they would use different modes for high-value, low-weight goods than compared to low-value, high-weight goods. These distinctions are often constant within a commodity classification.

Standard Transportation Commodity Classification

The STCC system was developed in the early 1960s by the American Association of Railroads (AAR) to analyze commodity movements by rail. The AAR used this system to identify commodities to assign rates for rail carriers regulated by the Interstate Commerce Commission (ICC). The STCC continues to be used by the AAR as a tariff mechanism. The Commodity Flow Survey (CFS), and its predecessor, the Commodity Transportation Survey, used STCC codes through 1993. The STCC is a hierarchical system, where additional digits provide more detail within the same commodity. For example, STCC 23 is apparel while STCC 2330 is women's or children's clothing. More detail on the STCC, including the definition of individual STCC codes, can be found at https://www.railinc.com/rportal/standard-transportation-commodity-code.

Changes over the last 25 years have gradually made the STCC code less useful for tracking domestic product movements across all modes (although it remains functional for tracking rail-only movements). These changes include the deregulation of trucking, the enactment of the North American Free Trade Agreement (NAFTA), changes in logistics practices, the emergence of plastics and composite materials that replaced metals and glass, the obsolescence of many categories of wood products, and the rapid recent development of high-tech electronic goods.

Standard Classification of Transported Goods

U.S. agencies and the Canadian Governments created the SCTG coding system for product classification to better reflect the changing landscape of goods movement. Like the STCC, it is a hierarchical system where additional digits provide additional subclassifications of commodities. The CFS uses the SCTG system to report sub classifications of freight; survey respondents identify freight at the five-digit SCTG level. The CFS serves as a primary source for the development of the FAF, so the FAF also relies on the SCTG system; FAF summaries report commodity flows at the two-digit SCTG level. More information on the SCTG system, including the definitions of the individual codes, can be found at https://www.bts.gov/sites/bts.dot.gov/files/docs/browse-statistical-products-and-data/surveys/commodity-flow-survey/210866/2017-cfs-commodity-code-sctg-manual.pdf.

The Harmonized System

The Harmonized System (HS) is an international nomenclature for the classification of products. It allows participating countries to classify traded goods on a common basis at customs. The HS for classifying goods is a hierarchical system with up to six-digits of coding. The first two digits (HS-2) identify the chapter in which the goods are classified (e.g., 09 = Coffee, tea, maté and spices); the next two digits (HS-4) identify groupings within that chapter (e.g., 09.02 = Tea, if flavored); The next two digits (HS-6) are even more specific (e.g., 09.02.10 Green tea [not fermented]). The HS was introduced in 1998 to provide consistent reporting of international goods and collecting custom fees. The creators of the SCTG system reviewed the HS and shares many similarities. More information on the HS can be found at https://hts.usitc.gov/current.

Performance Monitoring System

Military and waterborne commerce often uses the Performance Monitoring System (PMS), which is a refinement of the information collected for locks and dams. The preparers of the FAF considered the PMS method of information conversion in their development. Practitioners using the QRFM will rarely encounter this system.

Other Commodity Systems

There are other commodity systems in use in international settings, such as the Standard Trade International Classification (STIC) and the Broad Economic Categories (BEC), but these have largely been supplanted by the HS system. QRFM users will rarely encounter these classification systems.

Goods may be classified as hazardous materials (HAZMAT), which requires special consideration during transport. However, commodity databases rarely report HAZMAT and normally they are not included in freight forecasting methods. HAZMAT is a subset of the commodity classifications. For example, one shipment of SCTG 20 Basic Chemicals may be classified as HAZMAT because of its characteristics, while another shipment of SCTG 20 might not be considered hazardous. Information concerning the transport of HAZMAT is often a matter of security and not disclosed publicly; this makes it challenging to include HAZMAT in freight forecasting methods.

TRUCK CLASSIFICATION SYSTEMS

In the QRFM, trucks are both a mode that carries freight and a mode that serves non-freight purposes. Classification of trucks is often necessary in different applications. For example, pavement analysis may require truck classification based on their axle weight. Because there are many different applications, there is no common system used to classify trucks. The classification system may depend on attributes that can be readily observed and the intended use of the data. Classification schemes may consider:

- The weight of the truck.[3]
- The number of axles and tires of the truck.
- The body type of the truck.
- The length of the truck.
- The commercial markings on the side of the truck and/or its trailer.
- The purpose of the truck's trip.
- The power of the engine in the truck.
- The type of fuel powering the truck.
- The contents of the cargo area of the truck.

The selection of a truck classification scheme could lead to compatibility issues when merged with other data sources in a forecasting or analysis exercise. Weigh in motion (WIM) stations observe the weight of the truck when it passes through that WIM station. Departments and Registries of Motor Vehicles (DMV/RMV) report the gross vehicle weight (GVW), the maximum weight of the vehicle, cargo, and passengers as specified by the truck manufacturer. Pavement engineers require the weight per axle of various types of trucks. The FHWA's Traffic Monitoring Guide (TMG) outlines a truck classification system based on the number of axles, tires, and the general body type (see figure 3). Some State Departments of Transportation (DOTs) classify trucks based on the length of the truck and its trailers. Video or visual observations often classify a truck based on the marking on the side of the truck. Commercial vehicle surveys may be the only data source that includes truck travel purpose, and only for the sample of trucks surveyed.

This can lead to classification systems that are incompatible. Two trucks may have a beverage truck body, but the TMG classifies the first truck as a class 5 (single unit with two axles and five tires), while it classifies the second truck as a class 8 (combination unit, one trailer; three axles in total). Both trucks will have a different weight per axle depending on whether they are loaded or empty.

[3] Weight may vary from the weight at the time of observation to the maximum weight that can be legally transported or to the average weight per axle.

Even though GVW-based classifications consider light trucks, many agencies do not consider any vehicle with a GVW less than 10,000 pounds to be a truck. The National Highway Traffic Safety Administration (NHTSA), the Federal Motor Carrier Safety Administration (FMCSA), and the FHWA use that weight limit to define trucks. Table 1 provides a summary of FHWA's classes based on GVW.

Several agencies have tried to reconcile the different truck classification systems. The Environmental Protection Agency (EPA) reviewed the FHWA/TMG classification system to make it compatible with weight-based classification systems, but they observed that there is considerable overlap between these systems.[4] Because of these disparities, there is no single recommended truck classification system; practitioners could select the truck classification system that best suits their needs and available data.

Table 1. Vehicle identifiers and typical average vehicle weight range.

FHWA		**Observed GVW Range (lbs.)**	**GVW Classes**
Class Description Average Vehicle Weight (lbs.)			
1	Motorcycles	8,000–25,000	1
2	Passenger vehicles	4,500–9,000	1 and 2
3	Two-axle, four-tire single-unit trucks	7,000–9,000	2 and 3
4	Buses	25,000–29,000	6 and 7
5	Six-tire, two-axle single-unit vehicles	12,000–14,000	4 and 5
6	Three-axle single-unit vehicles	24,000–30,000	6 and 7
7	Four or more axle single-unit vehicles	41,000–58,000	8
8	Three or four axle single-trailer vehicles	26,000–31,000	7
9	Five-axle single-trailer vehicles	48,000–58,000	8
10	Six-axle single-trailer vehicles	60,000–65,000	8
11	Five or less axle multi-trailer vehicles	50,000–61,000	8
12	Six-axle multi-trailer vehicles	56,000–63,000	8
13	Seven or more axle multi-trailer vehicles	72,000–92,000	8

4 ENVIRON International Corporation, Development Work For Improved Heavy-Duty Vehicle Modeling Capability Data Mining—FHWA Datasets, U.S. Environmental Protection Agency, July 2007.

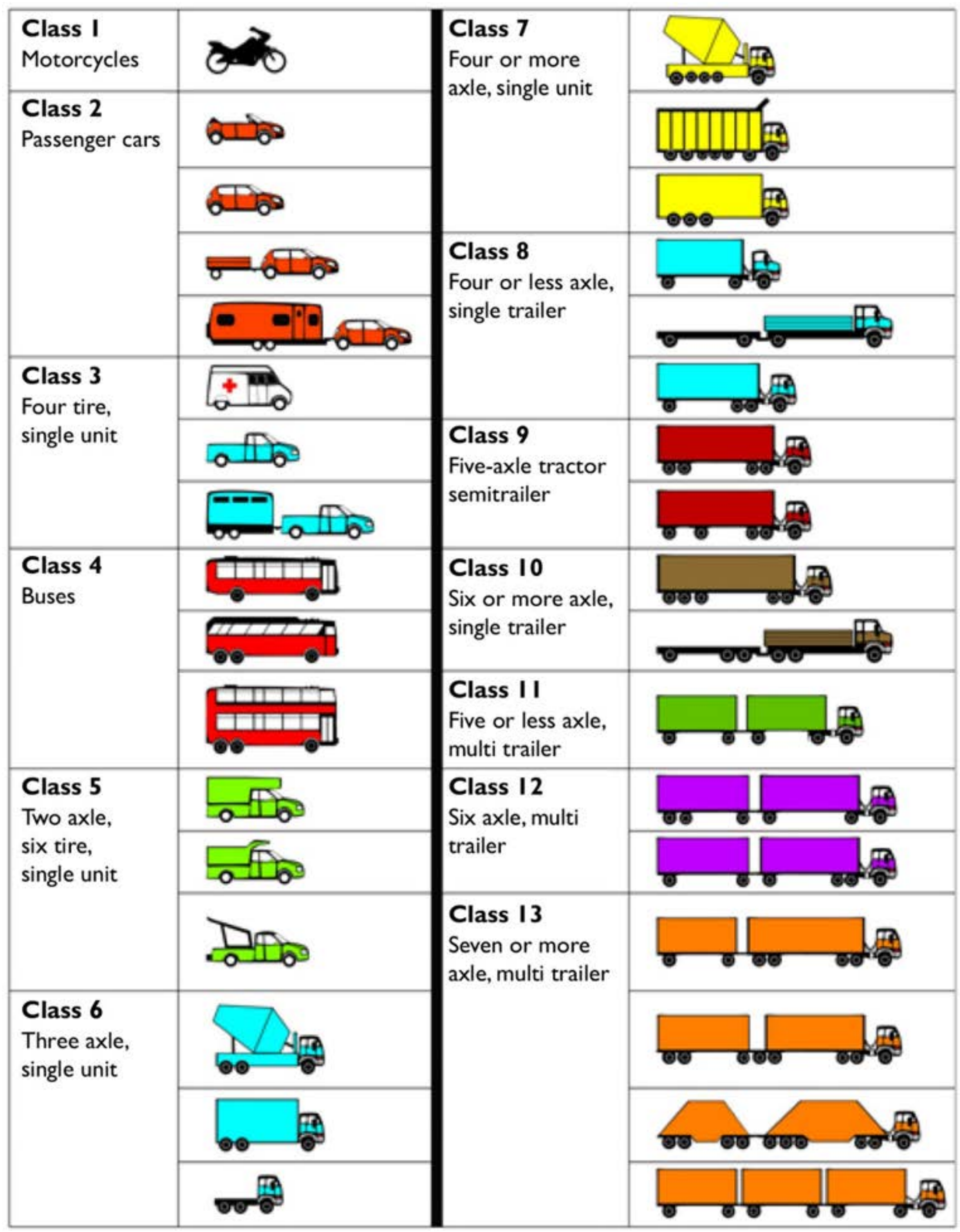

Figure 3. Diagram. Federal Highway Administration 13 vehicle category classification. (Source: Federal Highway Administration.)

SIMILARITIES BETWEEN PASSENGER AND FREIGHT PLANNING AND MODELING

Practitioners with experience passenger forecasting are often reluctant to consider themselves freight forecasters. However, the concepts and methods used in freight forecasting are similar to those used in passenger forecasting. Practitioners who are familiar with passenger modeling may recognize that the freight forecasting process uses roughly equivalent concepts and terms. Table 2 shows passenger modeling terms and their equivalent in freight/truck modeling.

Table 2. Table of passenger and freight modeling terms.

Passenger Modeling Terms	Freight/Truck Modeling Terms
Daily Person Trips	Annual Tons
Purposes	Commodities
Production and Attraction	Produced and Consumed
Population and General Employment	Population and Detailed Industry Employment
Household Survey	Commodity Flow and/ or Commercial Vehicle Surveys
Auto Occupancies	Payload Factors
Auto Volumes	Truck Volumes
Passenger Tours	Supply Chains (freight) Truck Tours (non-freight)
Passenger Agents	Shipper-Receiver Agents (trip table) Carriers (assignment)

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CHAPTER 3. FREIGHT DEMAND AND PERFORMANCE—CONTROLLING FACTORS

This section of the *Quick Response Freight Methods* (QRFM) update provides a detailed discussion of the controlling factors that impact freight demand analysis and forecasting. These factors can be broadly grouped into the following categories:

- **Economic Structure—**Who moves freight?
- **Industry Supply Chains and Logistics—**Where does freight move?
- **Freight Infrastructure/Modes—**How does freight move?
- **Freight Traffic Flows—**What and how much freight is moved?
- **Organization and Public Policy—**Why does freight move the way it does?

Practitioners need to understand how these factors impact freight demand to perform a policy-sensitive freight demand analysis and develop reliable freight forecasts for planning purposes. Practitioners can also use these factors to inform variable adjustments that better reflect different forecasts and scenarios.

ECONOMIC STRUCTURE

Who Makes the Decision to Produce or Attract Freight?

This question directly relates to the economic sectors that make or use freight in a region; the type and amount of economic activity in a region correlates with the region's freight demand. Goods production and consumption in an area and the relationship between producers, consumers, and intermediate suppliers impact the magnitude and spatial distribution of freight flows. The dependence of freight demand on economic structure is better understood by considering the following components of the economy, and analyzing their specific impacts on freight flows:

- Types of industries.
- Personal consumption.
- Trade activity.
- Variables that can be changed.

Types of Industries

Freight demand is a direct function of the types of industries in a region. The types of industries in an economy can be broadly classified into manufacturing, resource production (e.g., mining, oil/gas), and service industries; each industry has a unique impact on freight flows. Goods production industries, for example, have various types and quantities of goods produced and consumed, and they use various transportation services to meet the demand for production inputs and supply of outputs. Warehousing and distribution activities, big-box retail, hospitals, and other institutions also drive freight demand, especially in and around metropolitan areas.

Transportation services in a region provide the supply to meet freight transportation demand, which impacts the characteristics of modal freight flows such as the types of equipment and time-of-day activity. Trucking flows generated by service industries in urban areas may account for a significant share of total trucking activity, and practitioners need to consider this in urban freight (truck) models to accurately predict total trucking demand on the highway network. Service-related trucking has unique types of equipment and time-of-day activity, which are important variables to consider when analyzing trucking activity in a region.

Personal Consumption

Personal consumption is another important component of an economy that can impact freight demand; it is driven by economic growth and generates demand from households for goods and services. This demand translates to increased retail activity, which is a major generator of local truck trips, especially in urban areas. Freight flows associated with retail activities also have unique trip distribution and trip chaining patterns, which are important parameters to consider when developing urban freight models. Personal consumption is a key data element in economic input-output models, providing the total household consumption of goods and services. Planners can use this information to analyze the total freight demand associated with personal consumption activity, including first and last mile movements that are more tied to personal consumption.

Practitioners could distinguish between goods-to-service personal consumption and the freight transportation used to service personal consumption. Freight commodity databases may not consider the goods shipped to a home as freight, which means that they may not capture the e-commerce goods and services. The total personal consumption demand may be the same within a region, but the destination of goods classified as freight may change.

E-commerce is blurring the lines between personal and freight activities as well as the origins and destinations of freight. E-commerce is an emerging analysis area which warrants further study.

Trade

Trade activity is a critical component of the economic structure of a region and can be divided into three broad categories—international, domestic, and local. Each trade category has distinct freight demand characteristics such as the origin-destination (O-D) patterns of shipments, commodities handled, modes used, types of facilities used, length of haul, size of shipments, and time dependencies. For example, the trucking mode dominates local trade in a metropolitan area; it has different facility usage compared to international shipments, which have significant intermodal marine and rail activity and logistics operations with unique facility usage such as container freight stations (i.e., a freight [de]consolidation facility like a warehouse or a cross-dock usually serving a marine container terminal).

Variables That Can be Changed

Practitioners can change the socioeconomic data used to forecast freight demand by commodity; these variables are primarily characterized by the employment of firms in each zone in a study area and the population in those same zones. Practitioners can also vary the characteristics of the modal networks, such as the travel times, costs, and truck travel restrictions on individual links, and the reliability of different modes operating in a network.

INDUSTRY SUPPLY CHAINS AND LOGISTICS

Freight travel reflects the trading patterns connecting the production of freight and the attraction of freight, and it directly relates to the logistics and accessibility between the production and attraction regions.

There are important elements of industry supply chains and logistics that have a major impact on freight demand; critical considerations in developing freight forecasts include:

- Networks for distribution of commodity flows.
- Logistics actors and their interactions.
- Trends in supply chains and logistics.

Spatial Distribution Networks

Industry supply chains are characterized by spatial relationships, which dictate the spatial distribution of commodity flows. For example, the spatial organization of a retailer's distribution network influences the O-D patterns of freight flows moving through seaports as part of an international supply chain. Market areas typically influence these distribution patterns; for example, a new distribution facility location close to its customer market will affect regional freight flow. In terms of their importance in freight demand analysis and forecasting, these critical aspects of the supply chain directly impact the development of commodity flow databases, freight trip generation, distribution models, and freight traffic assignment.

When analyzing freight, practitioners can categorize freight generation (FG), freight trip generation (FTG), and service-trip generation (STG).

- **Freight Generation:** FG is derived from freight production-consumption (PC) and represents the goods required, measured in tons. This is the sum of freight attraction, the amount of cargo that is brought to the establishment to be processed, stored, or sold to customers, and freight production, the amount of cargo sent out of the establishment for use at another establishment.

- **Freight Trip Generation:** FTG is the number of freight vehicle trips needed to transport the goods generated by an establishment. Planners typically model FTG by converting FG to truck trips based on logistical decisions for shipment size, frequency of deliveries, vehicle size, and modes used. They use the models to derive trip generation based on the land use type of the commercial establishment generating the trips and the relationship between those subject sites, their commercial partners upstream and downstream within the PC link, and the land use and transportation system elements surrounding those freight-generating sites.

- **Service-Trip Generation:** STG is the number of vehicle trips generated when performing services at an establishment. It is virtually identical to the non-freight truck concept discussed in chapter 2.

Interactions between Logistics Players

Freight industry logistics decisions are shared by a host of players, including producer/receiver logistics managers, third-party logistics managers, integrated carriers, and the operators of intermodal terminals and their connections. The interactions between these logistics players impact freight demand characteristics such as the choice of modes, the size of shipments, the ports of call, the time of day, and frequency of shipments, which are critical elements for practitioners to consider when modeling freight transportation demand.

Supply Chain/Logistics Trends

Due to the dynamic nature of the freight logistics system, practitioners need to consider trends in industry supply chains, especially in freight forecasting. Important supply chain trends include shipper-carrier alliances impacting mode choice and increased outsourcing activity impacting freight and intermodal traffic through seaports. Historic trends in transportation productivity and the tradeoff between transportation and inventory lead to increased transportation service demand relative to industry output.

FREIGHT INFRASTRUCTURE/MODES

How is Freight Transported Between the Production/Shipper Zones and The Attraction/Receiver Zones?

This is often the last decision made by the shipper, carrier, and/or receiver. Each of the freight carrying modes provide different costs and types of service, which are the controlling factor when agents chose a mode or combination of modes to carry freight. These issues are important in isolation and they can dictate how supply chains combine modes. The shipper and/or receiver will decide among modes or among supply chains consisting of several modes. Important issues to consider include:

- **Demand Characteristics:** The origins served, destinations served, and shipment length.
- **Supply Characteristics:** The volume, frequency, cost, and special handling abilities.
- **Shipment Attributes:** Size of shipments, mode, Truckload (TL)/Less Than Truckload (LTL), pick-up and delivery times, special handling considerations, and shipment value.

These factors are discussed in more detail separately for the trucking, rail, marine, and air cargo modes.

Trucking

Operational characteristics of the trucking industry pertaining to market area, type of carrier, and type of service impact various elements of trucking freight demand. When analyzing freight demand by market area, trucking dominates the short-haul freight market due to its flexibility and cost relative to other modes. For this reason, many urban freight models are "truck" models and do not involve a mode share component.

Trucking operations are often categorized into for-hire TL, LTL, and private based on the type of carrier.

- TL shipments typically travel on only one truck with one destination, so delivery time estimates are often more accurate and faster compared to LTL shipping.
- LTL shipping allows multiple shippers to share space on the same truck. LTL is cost efficient, with multiple companies paying only for their portion of trailer space.
- Private shipments use trucks owned by the shipper.

Each of these carrier operations have distinct freight demand characteristics pertaining to the market areas, commodities handled, size of shipments, trip chaining characteristics, time-of-day traffic distributions, and freight facilities used.

In addition to hauling commodities, agents also use trucks for "service trucking." Urban models that include freight, local goods movement, and service vehicles are "commercial vehicle" models. Urban areas have significant service trucking activity and service trucks can account for a notable share of the total truck traffic in key locations. This has significant implications in the development of commodity-based urban truck models, which need to account for service-related truck traffic to accurately predict total truck traffic in the region. Distinguishing service trucks from freight trucks in empirical data can be difficult, and it demonstrates the need for more rigorous data collection through surveys for practitioners to determine the share of service versus cargo trucking on specific highway facilities.

Trucking involves a wide array of equipment, from small delivery vans and pick-up trucks to tractor-trailers and longer combination vehicles. The type of truck can vary based on the type of operation (service or cargo trucking), and type of commodity hauled by cargo trucks. For example, while tractor-trailers, Classes 8-13 in figure 3, are commonly used to carry long-haul freight, they also can perform local pick-up and delivery of goods. This has implications in the development of commodity-based truck models, particularly the use of accurate payload factors to convert commodity tonnages to equivalent truck trips. Truck equipment-type information can be important in the application of freight models for congestion, air quality, safety, and pavement impact analyses.

Practitioners can categorize the highway infrastructure into a shared-use or a truck-only facility based on the truck usage of the system relative to other vehicles. In a shared-use facility, trucks share the same network as autos and buses, which indicates the need to integrate passenger and truck models to predict the total traffic demand on the network. The type of infrastructure is a critical consideration in the analysis of key characteristics of freight flows on the network pertaining to travel times/speeds, reliability, safety, congestion, and related economic impacts.

The reliability of trucking is an important consideration. Planners characterize path reliability as the ability to meet a delivery window for a freight shipment with a predefined on-time delivery rate, such as 95 percent. For freight, agents often prioritize reliability over travel time due to the importance of on-time delivery of truck shipments. When a delivery time window is missed, it can have a costly ripple effect on the manufacturing process; agents often include additional buffer time in route planning because of this impact. The National Transportation Performance Management Program highlights the importance of system reliability and bottlenecks in freight trucking by including it as a performance measure.

Rail

Railroads are classified based on their operating revenue characteristics into Class I, II, or III. This classification is important in the analysis of rail freight demand, as each railroad class has distinct rail freight demand characteristics pertaining to the types of commodities handled, O-D patterns and length of haul, and size of shipments.

Two main categories of railroad service—carload and intermodal—are important determinants of rail freight demand; each category is associated with different commodities, service characteristics, logistics, and equipment.[5] Also, the rate of growth in rail freight demand for carload and intermodal freight differs, with intermodal rail demand rising at a much higher rate compared to carload demand. For these reasons, practitioners need to analyze rail carload and intermodal services separately, particularly when generating rail freight forecasts. Railroads may also offer carload service for a single commodity, such as coal or grain, called unit trains.

Figure 4. Photo. Rail Freight.
(Source: Getty Images.)

Unlike highway infrastructure, which is publicly owned, railroads own their private networks, control operations and maintenance (O&M), and make investment decisions on the networks, mainly for capacity enhancements. Because railway networks are privately owned and use proprietary railroad data, practitioners find analyzing the factors affecting railroad routing decisions and determining accurate link-level rail traffic flows on the network nearly impossible.

In addition to network track usage (mainline, spurs, and sidings), important railroad system elements include railroad terminals, intermodal lifts, and classification yards. Forecasting freight movements through these railroad facilities is critical to the overall rail system planning process and avoiding congestion and bottlenecks in the rail freight transportation network.

5 Carload is conventional train service in a variety of rail cars. Intermodal is specialized train service, transporting sealed containers or trailers on special rail cars. Intermodal cars are often operated in dedicated trains with faster service to specialized terminals.

Reliability in rail freight transport hinges on efficient train operations on those tracks able to meet a delivery window. Practitioners may not have the precise information, but they can express reliability as the percentage of time a delivery window is within a certain time parameter. Since private businesses make decisions that affect freight reliability and hold proprietary data, additional precision may not be possible.

Marine

The two main operational types of marine freight transportation include inland and large ocean shipping. These two operations involve different infrastructure (ocean versus inland waterway ports/terminals), types of equipment (vessels, barges, and terminal equipment), and unique types of commodities carried, shipment sizes, freight logistics/supply chains, and trading partners involved. Recent trends toward short-sea shipping services for domestic transportation between coastal cities on the west and east coasts of the U.S. indicate the importance of this form of ocean transportation to meet growing freight demand.

The main types of marine transportation services include bulk, break-bulk, container, and roll-on/roll-off, depending on the type of commodity carried. Freight demand analysis considers each of these services separately to address the need for distinct representation of commodity flows (e.g., tonnages, 20-Foot Equivalent Units [TEU],[6] and number of trucks) and support the analysis of land side impacts of marine freight flows; for example, land side traffic impacts of bulk transport differ from containerized transport because of differences in mode choices, equipment staging (e.g., chassis versus box in container shipping), and the size of shipments. Separating by type of service is essential for marine freight forecasting, since planners expect each service market to have different growth trends in the future (for example, containerized cargo has been the fastest growing group in marine transport).

Figure 5. Photo. Container Ship.
(Source: Getty Images.)

Vessel size is another important consideration in the analysis of marine freight demand. Vessel sizes have an impact on the port of call and land side traffic flows and provide key inputs for the analysis of environmental impacts, such as emissions, associated with marine transportation. Drayage by trucks provides a primary landside access for those marine vessels. While vessel size can vary, drayage trucks are approximately the same size. Large ports and large vessels will be served by more drayage trucks than smaller ports serving smaller vessels (in the absence of on-dock rail and dry ports). More detailed analysis will depend on the geographic level of detail of a forecast. The zonal location of other marine transportation system elements, including terminals, container yards, wharves, gates, and land side access routes, that play a critical role in the marine freight transportation system are useful elements in detailed freight modeling and forecasting process.

[6] TEU—20-Foot Equivalent Unit, a standard measure of container volume.

Air Cargo

Organizations use air freight systems to transport low weight, small volume, high-value cargo. Air cargo constitutes a small fraction of total freight tonnage but a higher fraction of total value of freight in domestic and international trade. Due to its high value, air cargo is travel-time sensitive, which means that slight changes in transit times can have significant cost impacts for air cargo shippers.

Operationally, air freight transportation tends to concentrate in larger metro area hubs, but it also involves freight movement through some regional freight-only airports. The analysis of hub activity in air freight transportation is important for the development of air cargo forecasts in metro areas. Larger metro airport hubs will attract aviation-linked businesses, including time-sensitive manufacturing, logistics, distribution facilities, and other supportive land uses. Hub activity is an important consideration in land side traffic impact modeling, since it generates significant truck trips in metro areas.

Air cargo operations can be divided into air cargo freighters, integrated carriers (e.g., FedEx), and cargo shipments in the belly of scheduled commercial carriers on passenger routes. These operations have distinct routing characteristics, time-of-day patterns, and underlying logistics frameworks.

Air-cargo terminals and sort facilities are other aviation system elements useful for the analysis of air cargo. Sort facilities may be located at off-airport sites, which generates truck trips and impacts truck traffic distributions. Forecasting truck flows and movements to and from these facilities is an important component of local freight planning.

Reliability in air freight movements is not just line haul air reliability, but also a measurement of how well airports serving air cargo meet a delivery window. Practitioners may not have the precise information, but they can express reliability as the percentage of time a delivery window is within a certain time parameter. Since private businesses make decisions that affect air freight reliability, such as transporting air cargo as belly cargo in scheduled passenger operations or in airplanes scheduled and dedicated to air cargo service, additional precision may not be possible.

FREIGHT TRAFFIC FLOWS

How Much Freight is Moved Between Regions?

The freight demand moving by individual modes or by a supply chain on modal networks may be expressed as tons, as ton-miles, or as tons converted into vehicles (e.g., tons converted to trucks using payload factors). Freight traffic can be represented in many ways, depending on the mode, type of vehicle/equipment, and commodity; these factors are specific to links on modal networks. The decisions affecting modal networks are often made by the common carrier moving freight, not by the shippers and receivers who create the demand for freight. If the service parameters between the shipper-receiver, (for example cost, shipment size, overall reliability, time of pick-up and delivery, special handling requirements, etc.) and the common carrier are met, the carrier often has great flexibility in routing decisions, (for example to address roadway congestion or link reliability issues).

Common representations are the number of vehicles (e.g., number of trucks and carloads for trucking and rail carload, respectively) and the height of those vehicles (e.g., height of a truck and double-stacked or single-stacked intermodal container railcars). Intermodal freight traffic is typically measured in twenty-foot equivalent units (TEUs) or forty-foot equivalent units (FEUs), where one TEU/FEU represents a standard 20-foot and 40-foot container respectively, while commodity-based representations of freight traffic involves measuring the total weight (tonnage) or value (dollars) of shipments for each commodity group.

Measures of freight traffic flows are important in freight demand analysis for a host of applications such as capacity, congestion, and safety impact analyses. For example, estimating the number of trucks on the network is essential for integrating truck flows with autos on shared-use networks and understanding congestion impacts. Freight traffic flows are key inputs for safety impact analyses, a critical component in the freight planning process for highway and rail modes. In the case of highways, the number of trucks on the network and their share relative to total traffic are important factors to understand when studying the interactions between truck and auto traffic and how they can impact safety.

The absence of integrated rail network models and the limitations of estimating rail flows on private rail networks make forecasting the safety implications associated with rail traffic particularly difficult. Typical approaches involve developing general rail traffic growth rates or relying on specific flow data from railroads to analyze rail/passenger conflicts.

Specific applications of freight traffic flow information in freight forecasting include trend analyses and trip generation estimation. Practitioners use historic measures of freight traffic flows to estimate growth rates based on a trend analysis approach to freight forecasting. They also use truck trips for facility-level freight forecasting by developing trip generation rates for truck trips as a function of facility characteristics such as employment and land area.

ORGANIZATION AND PUBLIC POLICY

What Factors Inform Freight Transportation Decisions?

Policy decisions can affect the shipper, receiver, and carrier, but these private entities will make decisions based on the needs of their business. While it is not reasonable to model individual business decisions, conditions in the aggregate, such as traffic congestion may influence the siting of commercial freight development in outlying areas without congestion. These organizational frameworks and their aggregate decision-making processes are useful for accurately modeling and forecasting freight flows in a region.

Public regulations can have a significant impact on freight flows in a region. For example, safety regulations such as route restrictions, truck size limits, and weight limitations influence routing patterns of truck movements, the types of equipment used, and shipment sizes. Environmental regulations pertaining to emissions impact equipment types, while hours of service regulations impact time-of-day characteristics.

Public land use regulations may have the most significant impact on freight demand, due to the inherent interrelationship between land use and transportation. For example, land use restrictions on warehousing facilities in a region can impact truck traffic patterns and trip length distributions.

Increased surveillance and inspection practices for freight shipments to meet security rules and regulations can find applications in modeling freight demand. For example, agencies are developing border and gateway simulation tools to provide key inputs to freight models for model calibration or validation. Security inspections and technology can create new data sources that practitioners can use to understand freight flow characteristics and model freight demand.

PART B. DATA

Data in the *Quick Response Freight Methods* (QRFM) are used to:

- Provide inputs for analysis methods including the networks and facilities that are used to transport freight by all modes and non-freight trucks.
- Estimate models and equations for freight and non-freight trucks that can be used to forecast the demand for freight across all modes and the demand for non-freight trucks.
- Calibrate and validate the models and equations developed for those methods.

Both the existing data sources that are described in chapter 4 and the new data sources that are described in chapter 5 can be collected, processed, and analyzed by agencies to support freight forecasting methods.

Both existing data and new data can be used to estimate and support the methods, but they can also be used to validate the forecasts from those methods.

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CHAPTER 4. EXISTING DATA

Data provides a key input element for freight planning and freight demand modeling, requiring planners and modelers to consider the right balance of national, local, and private data. The data used in freight planning and forecasting are predominantly drawn from public sources, such as the Federal Highway Association's (FHWA) Freight Analysis Framework (FAF). Although national datasets are generally the most complete and accessible, they lack the detail required for more specific and detailed analysis at a local or regional level. Local data sources provide a more comprehensive scale for these analyses, but require expensive data collection efforts and ongoing maintenance, as discussed in chapter 5. Finally, private sector data can provide insights into supply chains, but the data can be difficult to obtain given the privacy and confidentiality issues surrounding these data sources.

This chapter presents an overview of existing freight transportation data sources for use in the planning and analysis process, including a summary of the methodology and the major benefits and drawbacks of each approach. More specifically, this chapter discusses the following data:

- Data sources for commodity-level origin-destination (O-D) tables.
- Mode-specific data sources for freight.
- National-level freight networks and infrastructure data on existing facilities.
- Data on employment, wages, business patterns, and productivity measures.
- Performance data on highway monitoring, congestion and travel times.

MULTIMODAL COMMODITY ORIGIN-DESTINATION TABLES

There are several public and private sources for freight O-D data in the United States. This chapter discusses the three most commonly used sources: the FHWA's FAF, the U.S. Census Bureau/Bureau of Transportation Statistics' Commodity Flow Survey (CFS), and IHS Markit's TRANSEARCH Data. The discussion covers the general methodology used for each database and some of their major limitations. Overall, the FAF and TRANSEARCH databases differ in terms of the underlying source of data; their treatment of warehouse and distribution centers; the commodities reported; the treatment of multiple modes, origins, and destinations; and commodity classification schemes.

The nature of these databases differs and reflects the different source of data:

- FAF and CFS are closely related and they are both based on a survey of freight shippers.
- TRANSEARCH uses data shared by freight carriers as a key source of data.

The databases also treat movements at warehouses and distribution centers differently:

- Freight can be considered from the perspective of the cargo or from the perspective of a vehicle transporting that cargo. When freight cargo moves through a distribution center, it may be reported as two vehicle movements, where the origin of one movement and the destination of the next is the distribution center.

- The FAF database reports both movements using the same commodity, even if the movement from the distribution center consists of commodities moving in mixed shipments.
- TRANSEARCH uses a carrier focus. In addition to using the Standard Transportation Commodity Code (STCC) for most flows, it reports the movement from a distribution center in mixed commodities as its own unique commodity, designated as STCC 50XX instead of the FAF classification, which uses Standard Classification of Transportation Goods (SCTG) 43—Mixed Freight.

The databases also differ in how freight movements on multiple modes are reported:

- FAF defines a mode that includes multiple modes and in the case of truck-rail movements reports this mode as intermodal rail.
- TRANSEARCH reports each modal movement separately. Multiple movements include an origin and a destination at the zone of the modal transfer.

The treatment of the entire trip from origin to destination is also different:

- The FAF reports link freight movements from the ultimate origin to the final destination. These movements may be direct from the origin to the destination or they may have unreported intermediate stops where they pass through transfer centers and change mode.
- TRANSEARCH reports the individual segments of the trips, but not necessarily the origin and the destination of the freight.

The databases also differ in how freight flows and commodity movements are specified:

- The FAF includes reports of several commodities such as municipal solid waste, farm-based agriculture shipment, crude petroleum and refined gasoline, and supplies and materials used in construction (after the original purchase).
- TRANSEARCH includes many of these commodities but does not process them in the same manner as the FAF.

Since there are differences in the underlying source of data; the treatment of warehouse and distribution centers; the commodities reported; the treatment of multiple modes, origins, and destinations; and the commodity classification schemes, these databases are not interchangeable.

Freight Analysis Framework

The FHWA in partnership with Bureau of Transportation Statistics (BTS) developed and maintains the FAF to better understand freight demands, assess implications for surface transportation systems, and develop policy and program initiatives to improve freight efficiency. The FAF documents and forecasts the magnitude and geography of freight moving within the United States, analyzes changes in freight flows and networks, highlights mismatches in national and regional freight demand and supply, and details the regional significance of freight corridors and nodes. Since 2006, the FAF is based on the CFS, and both are prepared and released on a five-year cycle; the most recent release iteration is FAF4, which was released in 2015 with a base year of 2012. The first version of the FAF, released in 2002 with a base year of 1998, differed from later versions, as it was based on TRANSEARCH data instead of CFS data.

Beginning with FAF2, the framework reports flows between regions, which are State portions of the CFS reporting regions, plus international freight flows to Canada, Mexico, Latin and South America, Asia, Europe, the Middle East, and the rest of the world through the FAF regions as gateways. It provides seven mode classifications (truck, rail, water, air, pipeline, multiple modes, and other/unknown) and commodity data using the two-digit SCTG scheme to match the CFS.

The FAF is based entirely on public data sources and transparent methods; it has expanded to cover all modes and significant sources of shipments. The FAF also includes forecasts of freight flows in five year increments to a forecast horizon year that is typically 33 years from the base year (e.g., FAF4 with base year of 2012 also includes forecasts through 2045). The complete database and documentation are available online for downloading at https://ops.fhwa.dot.gov/freight/freight_analysis/faf/ and the database can be converted into an O-D table. For most of freight traveling by trucks on highways, that FAF O-D table is also assigned to the FAF highway network. The FAF4-assigned highway network reports the freight flows as daily trucks for the base year of 2012 and for the most distant forecast year of 2045. The loaded network is available at https://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf4/netwkdbflow/index.htm.

Table 3 outlines the features of the FAF.

This chapter uses the same tabular format to describe all the freight databases, which enables the reader to compare and contrast the features of each database along the same dimensions and determine the most appropriate source of data for each application.

Table 3. Freight analysis framework features.

Name	Freight Analysis Framework
Agency/Source	FHWA
Data Type	Transportation Statistics
Description	FAF integrates data from a variety of sources to create a comprehensive picture of freight movement among States and major metropolitan areas by all modes of transportation.
Data Coverage	FAF provides estimates of freight. Measures available in FAF include value, tons, and domestic ton-miles by mode of transportation, for type of commodity, between and within States or the 123 domestic FAF regions, and to and from 8 foreign regions for exports and imports.
Modes of Freight	Truck, Rail, Air, Water, Pipeline, Other
Commodities	SCTG Commodities
Years of Data	Since 1997 and it is based on the CFS as the primary data source.
Format of Data	Access Tables
Geographic Level	Consolidated Statistical Area or Metropolitan Statistical Area as defined by OMB and “rest of State”.

Table 3. Freight analysis framework features (continuation).

Name	Freight Analysis Framework
Temporal Factor	Once every five years.
Pricing	Free
Contact Info	FAF@dot.gov
Data Use	The FAF helps users understand the movements of freight between regions within the U.S. and between the U.S. and the rest of the world.
Data Overlaps	TRANSEARCH provides similar data but uses Standard Transportation Commodity Classification (STCC) instead of SCTG codes. Also, its data are available at the county level. Data can also be purchased from TRANSEARCH at the Zip code and TAZ levels.
Data Limitations	Temporal and spatial resolution makes it difficult to account for small geography as well as swings in the economy.
Forecast	Yes
Model Uses	Estimation—Yes; Calibration—Yes; Validation—Yes; Control Totals Available—Yes

Commodity Flow Survey

The Commodity Flow Survey (CFS) is conducted through a partnership between the U.S. Census Bureau, U.S. Department of Commerce, BTS, and U.S. Department of Transportation, producing data on the movement of goods in the United States. It provides information on:

- Commodities shipped.
- The value and weight of shipped commodities.
- Mode of transportation.
- The origin and destination of shipments of manufacturing, mining, wholesale, and select retail establishments.

Public policy analysts use the data from the CFS for transportation planning and decision making to assess the demand for transportation facilities and services, energy use, safety risk, and environmental concerns.

The public releases of the CFS are typically summaries that do not support detailed analysis. These releases can be obtained at https://bhs.econ.census.gov/bhs/cfs/?#. The 2012 CFS released an experimental dataset, the Public Use Microdata Sample (PUMS); this provided access to more detail and allows the computation of the variability in the CFS. The 2012 PUMS is available at https://www.census.gov/data/datasets/2012/econ/cfs/2012-pums-files.html.

Industry Coverage

The CFS covers business establishments with paid employees located in the United States that are classified using the North American Industry Classification System (NAICS). Examples include mining, manufacturing, wholesale trade, and select retail trade industries like electronic shopping and mail-order businesses. Establishments classified in services, transportation, construction, and most retail industries are excluded from the survey. Farms, fisheries, foreign establishments, and most government-owned establishments also are excluded.

The survey also covers auxiliary establishments (i.e., warehouses and managing offices) of multi-establishment companies, which have non-auxiliary establishments that are included in the CFS or classified in retail trade. Since the collection of industries included in the CFS has changed over time, comparisons between versions of the CFS should be made with caution.

Shipment Coverage

The CFS captures data on shipments originating from select types of business establishments located in the 50 States and the District of Columbia. The data do not cover shipments originating from business establishments located in Puerto Rico and other U.S. possessions and territories. Shipments traversing the United States from a foreign location to another foreign location (e.g., from Canada to Mexico) or to a U.S. location are not included.

The CFS includes imported products from the point that they left the importer's domestic location for shipment to another location. Shipments that are shipped through a foreign territory with both the origin and destination in the United States are included in the CFS data. The mileages calculated for these shipments exclude the international segments (e.g., shipments from New York to Michigan through Canada do not include any mileages within Canada).

The CFS includes export shipments with the domestic destination defined as the U.S. port, airport, or border crossing of exit from the United States.

Table 4 summarizes the major features, uses, and limitations of the CFS database in freight planning activities.

Table 4. Commodity flow survey features.

Name	Commodity Flow Survey
Agency/Source	The U.S. Census
Data Type	Transportation Statistics, National Level Shipper Surveys
Description	The CFS data are used by policy makers and transportation planners in various Federal, State, and local agencies for assessing the demand for transportation facilities and services, energy use, safety risk and environmental concerns. Additionally, business owners, private researchers, and analysts use the CFS data for analyzing trends in the movement of goods, mapping spatial patterns of commodity and vehicle flows, forecasting demands for the movement of goods, and determining needs for associated infrastructure and equipment.

Table 4. Commodity flow survey features (continuation).

Name	Commodity Flow Survey
Data Coverage	The CFS covers business establishments in the following industries: Mining, Manufacturing, Wholesale trade, Select Retail and Services. The survey also covers selected auxiliary establishments (e.g., warehouses) of in-scope, multi-unit, and retail companies. Industries not covered by CFS include transportation, construction, most retail and services industries, farms, fisheries, foreign establishments, and most government-owned establishments. Shipment coverage: The CFS collects data on shipments originating from within-scope industries, including exports. Imports are not included until the point that they leave the importer's initial domestic location for shipment to another location. The survey does not cover shipments originating from business establishments located in Puerto Rico and other U.S. possessions and territories.
Modes of Freight	Truck, Rail, Air, Water, Pipeline, Other
Commodities	SCTG Commodities
Years of Data	Since 1993 and conducted in years ending in 2 and 7.
Format of Data	Downloadable from American Fact Finder
Geographic Level	Consolidated Statistical Area or Metropolitan Statistical Area as defined by OMB.
Temporal Factor	Once every five years.
Pricing	Free
Contact Info	https://bhs.econ.census.gov/bhs/cfs/?#
Data Use	Used to analyze trends in goods movements over time, develop models and analytical tools for policy analysis and investment decisions, forecast future demand for goods movement, analyze and map spatial patterns of commodity and vehicle flows.
Data Overlaps	
Data Limitations	Temporal and spatial resolution makes it difficult to account for small geography swings in the economy.
Forecast	No
Model Uses	Estimation—No; Calibration—Yes; Validation—Yes; Control Totals Available—Yes

IHS TRANSEARCH

TRANSEARCH is a privately maintained market research database for intercity freight traffic flows compiled by IHS Markit. The data are compiled from scores of sources including traffic information shared by freight carriers. In freight, carriers are the agents that make decisions on routing and assignment, but do not influence the production or attraction of freight which is reflected in the freight trip tables.

TRANSEARCH reports freight flows by a single mode and are not linked into tours. It reflects freight flows as beginning or ending at transfer terminals where freight flows change modes. It reflects carrier decisions that may not be reported in the trip tables and are derived from a survey of shippers and receivers. The database includes information describing commodities (by Standard Transportation Commodity Classification [STCC] code), tonnage, origin and destination markets, and mode of transport. TRANSEARCH obtains data from Federal, State, provincial agencies, trade and industry groups, and a sample of rail and motor carriers. Forecasts of commodity flows for up to 30 years are available.

Agencies generally accept TRANSEARCH data as the most detailed, readily available commodity flow data, by both commodity and geography; States, metropolitan planning organizations (MPO), and the FHWA use these data to conduct freight planning activities. However, it should be noted that there are some limitations to how these data can be used and interpreted.

- **Mode Limitations—**The rail waybill data used in TRANSEARCH are from the Carload Waybill Sample (described below) and based on data collected by Class I railroads. The waybill data contained some information for regional and short-line railroads, but only those related to interline service associated with a Class I railroad. Therefore, the rail tonnage movements provided by the TRANSEARCH database are conservative estimates.

- **Use of Multiple Data Sources—**TRANSEARCH consists of a national database built from company-specific data and other available databases. To customize the dataset for a given region and project, analysts incorporate local and regional data sources. This incorporation requires assumptions that sometimes compromise the accuracy of the resulting database. Different data sources use different classifications; most economic forecasts are based on North American Industry Classification System (NAICS) codes, while commodity data are organized by STCC codes. These and other conversions can sometimes lead to data being miscategorized or left unreported.

- **Data Collection and Reporting—**The level of detail provided by some individual companies when reporting their freight shipment activities limits the accuracy of TRANSEARCH. If a shipper moves a shipment intermodally, then analysts must identify one mode as the primary method of movement. Suppose three companies make shipments from the Midwest U.S. to Europe using rail to New York then water to Europe:

    - One company may report the shipment as simply a rail movement from the Midwest to New York.
    - Another may report it as a water movement from New York to Europe.
    - A third may report the shipment as an intermodal movement from the Midwest to Europe with rail as the primary mode.

The various ways in which companies report their freight shipments can limit the accuracy of TRANSEARCH:

- **Limitations of International Movements—**TRANSEARCH does not report international air shipments through regional gateways. Additionally, specific origin and destination information is not available for overseas waterborne traffic through marine ports. TRANSEARCH does not identify overseas ports and it estimates the domestic distribution of maritime imports and exports. TRANSEARCH data do not completely report international petroleum and oil imports through marine ports.

While TRANSEARCH itself is not publicly available, more information on TRANSEARCH can be found at https://ihsmarkit.com/products/transearch-freight-transportation-research.html.

Table 5 summarizes the major features, uses, and limitations of the TRANSEARCH database in freight planning activities.

Table 5. TRANSEARCH database features.

Name	TRANSEARCH
Agency/Source	IHS Markit
Data Type	Transportation Statistics
Description	TRANSEARCH is an annual database of U.S. county-level freight movement data used for freight modeling and forecasting.
Data Coverage	TRANSEARCH includes market-to-market flow data for more than 450 individual commodities and seven modes of transportation at the county level.
Modes of Freight	Truck, Rail, Air, Water, Pipeline, Other (6 modes)
Commodities	STCC Commodities
Years of Data	Since 1995 and available yearly.
Format of Data	Access database
Geographic Level	U.S. County and BEA regions (outside of geography of interest).
Temporal Factor	Annual
Pricing	Ranges from $28,000 to $200,000
Contact Info	844-301-7334
Data Use	Data are used to analyze trends in goods movements over time, develop models and analytical tools for policy analysis and investment decisions, forecast future demand for goods movement, and analyze and map spatial patterns of commodity and vehicle flows.
Data Overlaps	FAF provides similar data but uses SCTG instead of STCC codes and data is not available at traffic analysis zone (TAZ) level in the standard tables but available as special tabulations.
Data Limitations	Methodology is not very transparent to the user of the database.
Forecast	Yes
Model Uses	Estimation—Yes; Calibration—Yes; Validation—Yes; Control Totals Available—Yes

DISAGGREGATION OF COMMODITY ORIGIN-DESTINATION TABLES

The commodity O-D data described in chapter 3 are available for specific geographies. In the case of the FAF, the 132 internal U.S. and 8 international regions that are available may be too coarse for estimating freight demand and usage (see figure 6). Practitioners have proposed and applied various methods to disaggregate these O-D flows into smaller geographies.

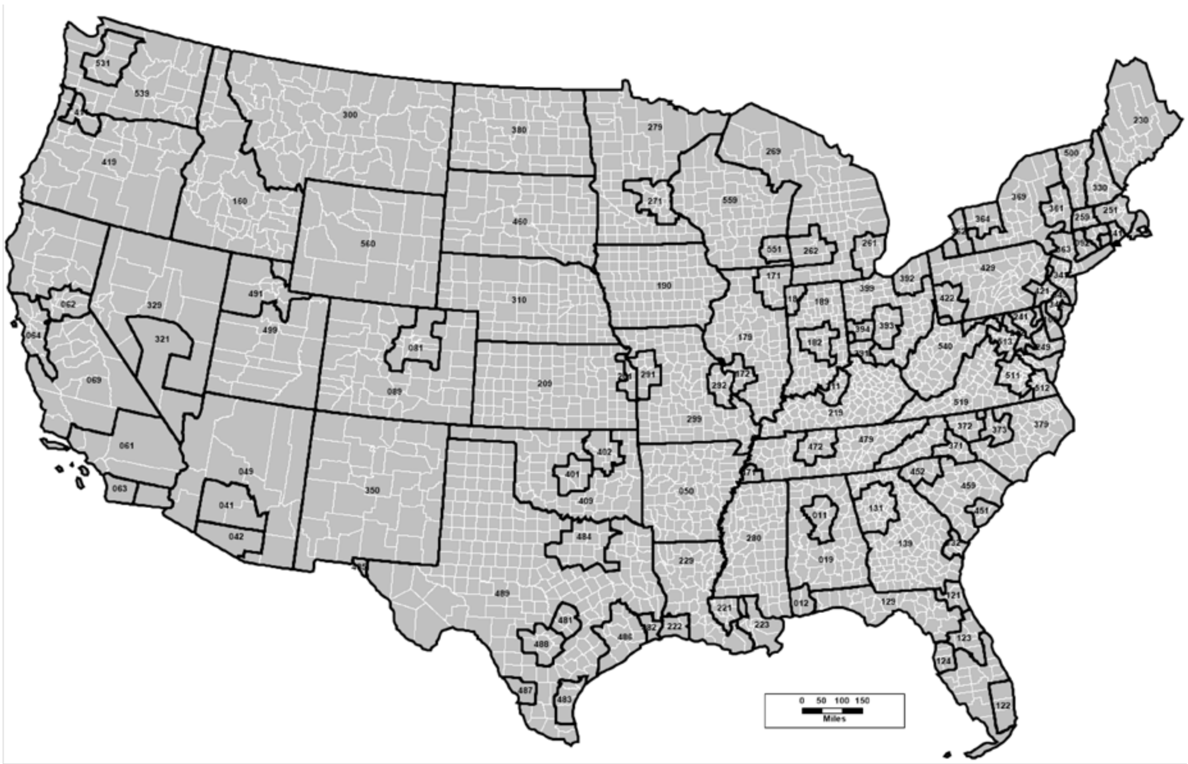

Figure 6. Map. Freight analysis framework zones.
(Source: https://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf4/netwkdbflow/index.htm.)

Disaggregation relates to the matrix/trip table expansion familiar to many practitioners with experience in passenger models. The process of splitting zones and expanding a passenger trip table to accommodate those splits is the same process used to disaggregate freight O-D tables. To disaggregate a trip table where the share of the flow unit is known, analysts can split or disaggregate the flow unit in the table (e.g., tons).

This same process can be used to expand/disaggregate freight O-D tables, such as the tables from a FAF region to the counties in that region. Practitioners have proposed equations that correlate the tons of a commodity produced or attracted with a zone based on the industry employment within the zone. These equations, which will be discussed in more detail as trip generation equations in chapter 9, can be used to estimate the tons in those smaller zones (e.g., counties) and then aggregated to the zones in a FAF region to calculate those shares. The size of the smaller zones is limited by the availability of employment by industry at the same level of geographic detail.

In most instances, employment information by industry is publicly available at the county level. Even if employment information is available for geographies smaller than a county, using it may not be advisable. The equations of production and attraction by industry by commodity are averages, so their accuracy relies on a large sample size of firms with employment in these zones. The smaller the zone, the greater the chance that the small number of firms in that zone will have rates (e.g., tons per employee) that differ from the industry average.

While this method alone is sufficient to disaggregate flows (i.e., split cells) that have domestic origins and destinations, the FAF also includes domestic zones as origins for imports and as destinations for exports. The disaggregation of these zones might differ depending on the foreign mode of transport. For example, if the foreign mode of transport is water, then the domestic gateway would be a port and analysts need to obtain the flows by tons of a commodity at the ports in a FAF region from another source.

MODE-SPECIFIC FREIGHT DATA

This section covers publicly available data that deal with specific modes, such as the Vehicle Inventory and Use Survey (VIUS), the Carload Waybill Sample for rail freight, and the U.S. Army Corps of Engineers' (USACE) Waterborne Commerce Statistics Database for water freight. As with the previous section, the discussion covers the general methodology used in each database and some of their major limitations.

Vehicle Inventory and Use Survey (VIUS)

The VIUS provides data on the physical and operational characteristics of the Nation's truck population. Its primary goal is to produce national and State-level estimates of the total number of trucks. The U.S. Census Bureau conducted the first survey in 1963 and the agency conducted it every five years beginning in 1967 and continuing to 2002. Prior to 1997, the survey was known as the Truck Inventory and Use Survey (TIUS). VIUS has not been included in the recent Economic Census, and the 2002 VIUS is the last national survey available. Several states have conducted their own more limited surveys to provide more recent information, for example California's CA-VIUS.

VIUS data are of considerable value to Government, business, academia, and the public. Organizations can use data on the number and types of vehicles and how they are used to study the future growth of transportation and calculate fees and cost allocations among highway users. The data are important for evaluating safety risks to highway travelers and assessing the energy efficiency and environmental impact of the Nation's truck fleet. The VIUS data can be used by businesses and others to:

- Conduct market studies and evaluate market strategies.
- Assess the utility and cost of certain types of equipment.
- Calculate the longevity of products and determine fuel demands.
- Link to and better utilize other datasets representing limited segments of the truck population.

Public use microdata sample files are available starting in 1977, and publications are available for all years.

Methodology and Limitations

The VIUS is a probability sample of all private and commercial trucks registered (or licensed) in the United States. The VIUS excludes vehicles owned by Federal, State, or local Governments; ambulances; buses; motor homes; farm tractors; and nonpowered trailer units. Additionally, trucks included in the sample but reported to have been sold, junked, or wrecked prior to the survey year (date varies) were deemed out of scope.

The sampling frame is stratified by geography and truck characteristics. The 50 States and the District of Columbia make up the 51 geographic strata. Body type and gross vehicle weight (GVW) determine the following five truck strata:

1. Pickups.
2. Minivans, other light vans, and sport utilities.
3. Light single-unit trucks (GVW 26,000 pounds or less).
4. Heavy single-unit trucks (GVW 26,001 pounds or more).
5. Truck-tractors.

Therefore, the surveyors partitioned the sampling frame into 255 geographic and truck type strata. Within each stratum, a simple random sample of truck registrations is selected without replacement.

Older surveys were stratified differently: for the 1963-1977 TIUS, the survey was stratified by "small trucks" and "large trucks." Printed copies of the older 2002 VIUS reports are available at https://www.census.gov/library/publications/2002/econ/census/vehicle-inventory-and-use-survey.html.

Table 6 summarizes the major features, uses, and limitations of the VIUS truck database in freight planning activities.

Table 6. Vehicle inventory and use survey database attributes.

Name	Vehicle Inventory and Use Survey
Agency/Source	U.S. Census Bureau
Data Type	Weight Data
Description	VIUS provides data on physical and operational characteristics of the nationwide private and commercial truck fleet. The physical characteristics data include weight, number of axles, overall length, and body type for medium and heavy trucks. The operational characteristics data include commodities handled, distance traveled, and mileage traveled.

Table 6. Vehicle inventory and use survey database attributes (continuation).

Name	Vehicle Inventory and Use Survey
Data Coverage	The VIUS excludes vehicles owned by Federal, State, or local governments; ambulances; buses; motor homes; farm tractors; and nonpowered trailer units. Additionally, trucks that were included in the sample but reported to have been sold, junked, or wrecked prior to the survey year were deemed out-of-scope.
Modes of Freight	Freight Trucks and Commercial Vehicles
Commodities	N/A
Years of Data	1997 and 2002 with versions of VIUS surveys dating back to 1963.
Format of Data	Access database
Geographic Level	State
Temporal Factor	The VIUS has not been updated since 2002 and there are no known plans to develop a new version.
Pricing	Free
Contact Info	https://www.census.gov/library/publications/2002/econ/census/vehicle-inventory-and-use-survey.html
Data Use	Used for development of truck payload factors.
Data Overlaps	Vehicle Travel Information System (VTRIS)
Data Limitations	Lack of more current data.
Forecast	No
Model Uses	Estimation—No; Calibration—Yes; Validation—Yes; Control Totals Available—No

Carload Waybill Sample

The Carload Waybill Sample is a stratified sample of carload waybills for terminated shipments by rail carriers. A waybill is a document issued by a carrier giving details and instructions relating to the shipment of a consignment of goods. Typically, it will show the names of the consignor and consignee, the consignment's point of origin, destination, route, method of shipment, and amount charged for carriage.

Railroads may file waybill sample information by using authenticated copies of a sample of audited revenue waybills (the manual system) or a computer-generated sample containing specified information (the computerized system or machine-readable input [MRI]). The waybill submissions from these two methods are combined in a 900-byte master record file containing a movement-specific confidential waybill file and a less detailed public use waybill file. The content of waybill requests are described in 49 CFR 1244.4. In summary, there are two levels of detail to the waybill: Confidential data that may be available, under certain conditions, and less detailed data that are always publicly available.

The waybill sample is a continuous sample that is released in yearly segments. For the past several years, the sample contained information on approximately 600,000 movements. It includes waybill information from Class I, Class II, and some of the Class III railroads. The Surface Transportation Board (STB) requires that these railroads submit waybill samples if, in any of the three preceding years, they terminated on their lines at least 4,500 revenue carloads. The waybill sample currently encompasses over 99 percent of all U.S. rail traffic.

Data from the waybill sample are used as input to many STB projects, analyses, and studies. Federal agencies such as the U.S. Department of Transportation and U.S. Department of Agriculture use the waybill sample as part of their information base. States also use the waybill sample as a major source of information for developing State transportation plans. In addition, nongovernment groups seek access to waybill sample data for uses such as market surveys, development of verified statements in STB and State formal proceedings, forecasts of rail equipment requirements, economic analysis, and academic research.

Because the master waybill file contains sensitive shipping and revenue information, access to this information is restricted to railroads, Federal agencies, States, transportation practitioners, consultants, law firms with formal proceedings before the STB or State boards, and certain other users. Rules governing access to waybill data are described in 49 CFR 1244.9.

Anyone can access the nonconfidential data in the public use file at https://www.stb.gov/stb/industry/econ_waybill.html.

Table 7 summarizes the major features, uses, and limitations of the Carload Waybill Sample freight rail database.

Table 7. Carload waybill sample attributes.

Name	Carload Waybill Sample
Agency/Source	Surface Transportation Board
Data Type	Transportation Statistics
Description	The Carload Waybill Sample is a stratified sample of carload waybills for all U.S. rail traffic submitted by those rail carriers terminating 4,500 or more revenue carloads annually.
Data Coverage	Under statue (49 CFR Part 1244) each railroad is required to file waybill sample information for all line-haul revenue waybills terminated on its lines if it terminates at least 4,500 revenue carloads in any of the three preceding years, or if it terminates at least 5% of the revenue carloads terminating in any State in any of the three preceding years.
Modes of Freight	Rail
Commodities	STCC Commodities
Years of Data	Since 1972 and available yearly. 2017 is the most recent data source.
Format of Data	ASCII Files
Geographic Level	Public file: BEA Regions; Confidential file: rail stations
Temporal Factor	Annual
Pricing	Free
Contact Info	https://www.stb.gov/stb/industry/econ_waybill.html

Table 7. Carload waybill sample attributes (continuation).

Name	Carload Waybill Sample
Data Use	Used to understand rail flows and to develop State transportation plans. Also used to develop TRANSEARCH rail trip tables.
Data Overlaps	None
Data Limitations	The Public Use Waybill Sample is restricted to BEA Regions. The confidential Waybill Sample data is available at the County level, but dissemination of the data is subject to approval by STB.
Forecast	2009, 2020, 2035, 2040 and 2050 Waybill Sample data. Since the dataset is confidential, data summaries cannot be provided in this report.
Model Uses	Estimation—No; Calibration—Yes; Validation—Yes; Control Totals Available—Yes

Waterborne Commerce Statistics Database

Every year, the United States Army Corps of Engineers' (USACE) publishes the Waterborne Databanks and Preliminary Waterborne Cargo Summary reports, which contain foreign cargo summaries including value and weight information by type of service on U.S. waterborne imports and exports. The USACE compiles these statistics based on the U.S. Bureau of the Census trade data matched to the U.S. Customs vessel entrances and clearances.

The Waterborne Commerce Dataset presents detailed data on the movements of vessels and commodities at the ports, harbors, waterways, and canals of the United States and its territories. The dataset aggregates statistics by region, State, port, and waterway for comparative purposes. Data on foreign commerce are supplied to the USACE by the U.S. Bureau of the Census, U.S. Customs, and purchased from the Journal of Commerce, and IHS Markit Port Import Export Reporting Service (PIERS).

Domestic Commerce

Contiguous and noncontiguous States and territories constitute the geographical space for the transportation of domestic commerce. This includes Hawaii, Alaska, the 48 contiguous States, Puerto Rico and the Virgin Islands, Guam, American Samoa, Wake Island, and the U.S. Trust Territories.

The waterborne traffic movements are reported to the USACE by all vessel operators of record on ENG Forms 3925 and 3925b (or equivalent), as approved by the Office of Management and Budget under the Paperwork Reduction Act (44 U.S.C. 3510[a]). Operators submit the reports based on individual vessel movements. For movements with cargo, the point of loading and the point of unloading of each individual commodity must be delineated. Cargo moved for the military agencies in commercial vessels is reported as ordinary commercial cargo; military cargo moved in Department of Defense vessels is not collected.

In summarizing the domestic commerce, certain movements are excluded, including cargo carried on general ferries; coal and petroleum products loaded from shore facilities directly into bunkers of vessels for fuel; and very small amounts of Government materials (less than 100 tons) moved on Government-owned equipment in support of Corps projects.

Foreign Commerce

Foreign commerce is waterborne import, export, and in-transit traffic between the United States, Puerto Rico and the Virgin Islands, and any foreign country. These statistics do not include traffic between any foreign country and the United States Territories and Possessions (American Samoa, Guam, North Mariana Islands, and U.S. outlying islands).

Beginning with the year 2000 publication, foreign waterborne import, export, and in-transit cargo statistics are derived primarily from data purchased from the PIERS, a division of the Journal of Commerce and currently an IHS Markit product, and supplemented by data furnished to the USACE by the U.S. Bureau of the Census and the U.S. Customs Service. Foreign cargo is matched to vessel move to improve geographic specificity. Table 8 summarizes the major features, uses, and limitations of Waterborne Commerce Statistics database.

Table 8. Waterborne Commerce Statistics database.

Name	**United States Army Corps of Engineers' Waterborne Commerce Statistics Database**
Agency/Source	United States Army Corps of Engineers
Data Type	Transportation Statistics
Description	Waterborne movements of a commodity tonnage from region to region.
Data Coverage	Ports, harbors, waterways, and canals of the U.S. and its territories.
Modes of Freight	Water
Commodities	Waterborne Commerce of the United States Publication commodity codes.
Years of Data	Since 1997 and available yearly. 2017 is the most recent database.
Format of Data	PDF Document
Geographic Level	Waterway/Region
Temporal Factor	Annual
Pricing	Free: USACE by the U.S. Bureau of the Census, U.S. Customs. Available for purchase from the Journal of Commerce, IHS Markit, Port Import Export Reporting Service.
Contact Info	https://www.iwr.usace.army.mil/About/Technical-Centers/NDC-Navigation-and-Civil-Works-Decision-Support/
Data Use	To understand the movements of waterborne freight between regions within the U.S. and between the U.S. and the rest of the world.
Data Overlaps	None

Table 8. Waterborne Commerce Statistics database (continuation).

Name	United States Army Corps of Engineers' Waterborne Commerce Statistics Database
Data Limitations	Geography below State is limited.
Forecast	None
Model Uses	Estimation—No; Calibration—Yes; Validation—Yes; Control Totals Available—Yes

Travel Monitoring Analysis System

The Travel Monitoring Analysis System (TMAS), formerly known as the Vehicle Travel Information System (VTRIS), validates, facilitates editing, summarizes, and generates reports on vehicle travel characteristics. It also maintains the permanent database of the station description, vehicle classification, and truck weight measurements. It allows for repetitive data averaging and report generation with different options without additional source data processing. It allows the input of electronic traffic data and import of State-submitted data in internal TMAS formats.

The information is presented in the series of TMAS/VTRIS W-Tables.[7] The FHWA designed these tables to provide a standard format for presenting the outcome of the vehicle weighing and classification efforts at truck weigh sites. Tables list the characteristics of each weight station and a summary of vehicles counted, vehicles weighed, average weight, and truck classification based on user input regarding State, year, and station or roadway classification.

The TMAS database and documentation can be accessed online at: http://osav-usdot.opendata.arcgis.com/datasets/cdd577d90e654e3098a73a91756e094e_0.

Table 9 summarizes the features of the Travel Monitoring Analysis System database.

Table 9. Travel Monitoring Analysis System database.

Name	Federal Highway Administration's Travel Monitoring Analysis System
Agency/Source	Federal Highway Administration
Data Type	Transportation Statistics
Description	Internal FHWA data program that assists in the collection and analysis of data on traffic volumes, vehicle classification, truck weights for traffic statistics, and analysis. It is used for development of policies and regulations. The monthly data are published in the Traffic Volume Trends (TVT) report. Previously known as the Vehicle Travel Information System (VTRIS).
Data Coverage	State submitted locations
Modes of Freight	Trucks only
Commodities	Combined
Years of Data	1990 to current.

7 https://www.fhwa.dot.gov/ohim/ohimvtis.cfm.

Table 9. Travel Monitoring Analysis System database (continuation).

Name	Federal Highway Administration's Travel Monitoring Analysis System
Format of Data	Available as download by State/location
Geographic Level	National, State, Urban, Rural
Temporal Factor	Annual
Pricing	Free by State by State
Contact Info	https://www.fhwa.dot.gov/policyinformation/travelmonitoring.cfm
Data Use	Developing payload factors for trucks
Data Overlaps	All trucks (freight and non-freight)
Data Limitations	Not submitted by all States
Forecast	None
Model Uses	Validation data

FREIGHT NETWORK/INFRASTRUCTURE DATA

The previous sections report freight flows carried by one or multiple freight modes. These freight travel flows, in the form of freight trip tables, can be assigned to modal networks to help understand the impact of freight transportation on infrastructure conditions and the constraints that the infrastructure places on freight movements.

This section discusses different types of networks that are available to assign freight flows. A network can be described as "routable" when each link is connected allowing a freight flow to traverse the entire length of the network.

Multimodal Freight Network

The U.S. Department of Transportation (USDOT) has Multimodal Freight Network (MFN) that consists of the line haul modal networks and the terminals where the modes on these networks can connect with other modes. The MFN is available for viewing at https://www.transportation.gov/freight/MFN. The MFN includes line haul networks for highway, railways, marine highways including coastal and inland waterways, airports, rail terminals, water ports, border crossings, and other locations where freight may change modes.

National Transportation Atlas Database

The most comprehensive public data are available through the National Transportation Database (NTAD) which provides the ability to download data by mode. While these modes do not exclusively transport freight, the datasets for these modes contain important freight components. For the terminals that provide connections between modes specifically for freight, the NTAD provides the ability to download data for these facilities including truck stop parking and intermodal facilities. The various datasets from the NTAD are available for download at http://osav-usdot.opendata.arcgis.com/.

National Transportation Research Center

In addition to the NTAD, the Oak Ridge National Laboratory's National Transportation Research Center, formerly the Center for Transportation Analysis, prepares modal networks and skim tables for use in transportation analysis, including FAF preparation. These modal networks and county-to-county "skim tables" show the level of service by each mode and are available at https://tedb.ornl.gov/. Information on modal networks is available directly from the modal agencies as well.

Table 10 summarizes the features of these three data sources and networks by providing a brief description of each, the coverage offered by the data, the freight modes, the format of the data, and the contact information for each database.

Table 10. Freight modal network and underlying data sources.

Name	Agency/ Source	Description	Data Coverage	Modes of Freight	Format of Data	Pricing	Contact info
Multimodal Freight Network (MFN)	USDOT	A good portion of materials and products move over multiple modes before reaching their destination. The USDOT has proposed a draft Multimodal Freight Network (MFN) that encompasses not only highways, but also the local roads, railways, navigable waterways, and pipelines, key seaports, airports, and intermodal facilities necessary for the efficient and safe movement of freight in our country.	National	Truck, Rail, Air, Water, and Pipeline	Downloadable GIS shapefile and PDF	Free	https://www.transportation.gov/freight
National Transportation Atlas Database	USDOT/ BTS	The National Transportation Atlas Database (NTAD), published by BTS, is a set of nationwide geographic databases of transportation facilities, transportation networks, and associated infrastructure. These datasets include spatial information for transportation modal networks and intermodal terminals, as well as the related attribute information for these features.	National	Truck, Rail, Air, Water, and Pipeline	Downloadable data sets (various formats)	Free	http://osav-usdot.opendata.arcgis.com/

Table 10. Freight modal network and underlying data sources (continuation).

Name	Agency/ Source	Description	Data Coverage	Modes of Freight	Format of Data	Pricing	Contact info
National Transportation Research Center/ Center for Transportation Analysis	Oak Ridge National Laboratory	NTRC offers industry, academia, and other agencies the opportunity to access state-of-the-art technologies, equipment and instrumentation, and computational resources to advance transportation technologies. These resources are critical to their efforts in the areas of improving fuel economy, reducing emissions and addressing transportation systems issues, such as traffic congestion, evacuation planning and highway safety.	National	Truck, Rail, Air, and Water	Downloadable data sets (various formats)	Free	https://www.ornl.gov/facility/ntrc

Sources for Mode Specific Nationwide Network/Infrastructure Data

Federal Highway Administration

The Federal Highway Administration (FHWA) maintains several highway networks for various purposes, including the National Highway Planning Network (NHPN), a network of the most important highway segments and their attributes; the Highway Performance Monitoring System (HPMS) network, which is developed from State submittals of inventory data; and the FAF highway network, which is an assignment of the FAF O-D table for trucks to the most important highway freight segments. These networks are available through the NTAD website for highways at http://osav-usdot.opendata.arcgis.com/datasets?keyword=Highway.

Federal Railroad Administration

The Federal Railroad Administration (FRA) data viewer at https://fragis.fra.dot.gov/GISFRASafety/ advances their safety mission, but it also includes layers for grade crossings, freight stations, and main line railways (including Class I Railroads). Agencies can use this information to identify existing freight facilities.

U.S. Army Corps of Engineers Marine Freight

Waterborne commerce data are available from the U.S. Army Corps of Engineers at https://www.iwr.usace.army.mil/about/technical-centers/wcsc-waterborne-commerce-statistics-center/. These data provide reports of facilities, such as ports and waterways, as shapefiles and datasets that can be joined with other modal data.

Federal Aviation Administration

Data are available from the Federal Aviation Administration (FAA) on cargo at airports from https://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/previous_years/. These data provide reports of freight operations at airports and contains airport identifiers that allow analysts to connect them with other datasets.

EMPLOYMENT/INDUSTRY DATA

Agencies use population, employment, wage data, and income data to analyze and judge the economic development contributions that may result from a transportation improvement project. These analyses can include job trends, the types of industries that create new jobs in the region, a description of how existing businesses would be affected by the transportation project, and whether the local labor pool is sufficient to fill new jobs created by the project.

Within freight forecasting, analysts can use employment/industrial data as explanatory variables for freight movements and combine them with freight movement data from the FAF, CFS, or TRANSEARCH to estimate freight generation rates using regression equations and other methods.

Wage and payroll data by region are two variables that relate to the underlying economic activity in a region and the corresponding demand for freight and the goods movements that are produced and/or attracted in the region. These data can be used to analyze the differences in pay levels in one area compared to another, by occupation or by industry. When used in conjunction with unemployment rates, these data can indicate whether a region is in "economic distress." These data reflects the overall health of a region, especially if mean pay levels are significantly above or below State averages.

When viewed over time, wage and payroll data can show whether a region is gaining or losing ground relative to the State as a whole. An increase in economic activity is expected to result in an increase in freight flows and goods movements while a decline is expected to reduce freight activity. For poorer regions, a measure of economic progress can be wage levels that are progressively converging with the State average. As an economic development strategy, agencies can use transportation investments to reduce disparities among subregions in employment and wage growth. Economic development outcomes emanating from a freight transportation project may include relative increases in employment growth rates or relative reductions in unemployment rates.

This section provides an overview of the most common sources for employment, wage data, and income data.

Sources of Employment and Wage Data

Bureau of Labor Statistics

The Bureau of Labor Statistics (BLS), the principal fact-finding agency for the Federal Government in the broad field of labor economics and statistics, is an independent national statistical agency within the U.S. Department of Labor. It collects, processes, analyzes, and disseminates essential statistical data to the public, U.S. Congress, Federal agencies, and State and local Governments. The BLS works with State-level employment agencies throughout the country to collect data on employment, unemployment, and wages. Statistics can be obtained from the Bureau's website at https://www.bls.gov/.

State Department of Labor

Individual State Departments of Labor (DOLs) are the chief collector of data on industry and regional employment trends in their State. Agencies usually collect data through several distinct programs, in cooperation with the BLS. While these data are also available from the BLS, State DOLs may be a source of detailed employment data that have not been submitted to the BLS.

Current Employment Statistics

Current Employment Statistics (CES) is a national data source collected through a monthly survey of about 160,000 business and Government agencies representing approximately 400,000 individual work sites. CES provides detailed industry data (industry-level details are available at a four-digit NAICS code for some larger metropolitan areas) on nonfarm employment, hours, and earnings estimates based on payroll records. Current data on employment are available for most industries. Because comparable data are collected for all States and metropolitan areas, CES is an excellent source for evaluating and comparing the economic health and composition of these larger geographic areas; however, CES data generally are not available at the county level. CES data are available at https://www.bls.gov/ces/data/home.htm.

Local Area Unemployment Statistics

The BLS produces these monthly figures that provide labor force estimates, including the number of persons employed, the number of persons unemployed, and the unemployment rates for areas in the United States. Information is available for States, metropolitan statistical areas, counties, and some cities, towns, and villages. The data from the Local Area Unemployment Statistics (LAUS) are particularly helpful if analysts use “high unemployment rates” (a proxy for “economic distress”) as selection criteria for evaluating the economic development component of a transportation project.

One significant difference between the LAUS data series and the other employment sources discussed in this section is that LAUS data use a household survey instead of an employer survey. Because the LAUS is a household survey, it reflects where employed and unemployed people *live*, not where they *work*.

LAUS data are available from the BLS’s website: https://www.bls.gov/lau/data.htm.

The following definitions for *civilian labor force and employment* are used in the Local Area Unemployment Survey:

- **Civilian Labor Force—**The portion of the population age 16 and older employed or unemployed. The BLS considers a civilian unemployed if they are not working, despite being willing and able to work, and actively seeking work.

- **Employment (Total)—**The estimated number of people in an area who work for pay or profit during a period, or who had jobs from which they were temporarily absent, or who worked 15 hours or more as unpaid family workers.

Occupational Employment Statistics

Occupational wage data are produced by the BLS in cooperation with each State’s Department of Labor. The program produces employment and wage estimates for over 800 occupations. These are estimates of the number of people employed in certain occupations and the wages paid to them; self-employed persons are not included in the estimates. These estimates are available for the Nation, individual States, and metropolitan areas; national occupational estimates for specific industries also are available.

Data are generated through a voluntary survey of employers that are analyzed by the BLS to produce wage data for the regions. The data are available at the following site: https://www.bls.gov/oes/tables.htm.

U.S. Census Bureau's County Business Patterns

County Business Patterns (CBP) is an annual series from the U.S. Census Bureau that provides subnational economic data by industry.[8] Its name is a holdover from earlier times when counties were its finest reporting area; today, data are available by zip code. The series is useful for studying the economic activity of small areas and analyzing economic changes (employment, number of business establishments, and payroll by industry) over time.

Analysts can access CBP data for the U.S., individual States, metropolitan areas, and at the zip code level by using a menu-driven website maintained by the Census Bureau: https://www.census.gov/programs-surveys/cbp/data/datasets.html. Confidentiality requirements for certain combinations of industries and geographies may require the suppression of employment data in the public releases. In cases where economic data are derived from a small number of firms, the analyst needs to apply methods to estimate suppressed data to develop data for a study area.

Economic Census Industry Data

The Census Bureau conducts the Economic Census every five years, in years ending in "2" and "7," to provide data on the national economy by major industry sector. The CFS is a primary data source for the FAF and is part of this Economic Census, a comprehensive dataset that presents detailed industrial data at the State, metropolitan area, and community levels and is consistent with the commodity flows reported in the CFS or FAF. Since the Economic Census is released every five years, there is a lag time of several years between the time the data are gathered and the time they are published.

Reports can be obtained directly from the Census Bureau site at https://www.census.gov/programs-surveys/economic-census.html. The Census includes tables reporting data on establishments, sales, and payroll at the State, metropolitan area, county, and community levels.

Table 11 summarizes the discussion in this section by presenting the five different sources of employment data with a brief description of each database, the geographic resolution of the data, and the frequency with which each data sources is collected.

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[8] The County Business Patterns program defined industries under the Standard Industrial Classification (SIC) system through 1997. However, beginning with the 1998 CBP program (published in 2000) data were tabulated using the North American Industrial Classification System (NAICS).

Table 11. Sources of employment data.

Name	Description	Geographic Level	Temporal Factor	Contact info
Bureau of Labor Statistics[1]	The Bureau of Labor Statistics (BLS) is the principal fact-finding agency for the U.S. government in the broad field of labor economics and statistics and serves as a principal agency of the U.S. Federal Statistical System.	National, State, County and Metro Area		https://www.bls.gov/
Current Employment Statistics (CES)	The Current Employment Statistics (CES) program produces detailed industry estimates of nonfarm employment, hours, and earnings of workers on payrolls.	National, State and Metro Area, and about 450 metropolitan areas and divisions.	Annual, Monthly	https://www.bls.gov/ces/data.htm
Local Area Unemployment Statistics (LAUS)	The Local Area Unemployment Statistics (LAUS) program produces monthly and annual employment, unemployment, and labor force data for Census regions and divisions, States, counties, metropolitan areas, and many cities, by place of residence.	Statewide, Metro Area, County, City (top 50)	Annual, Monthly	https://www.bls.gov/lau/data.htm
Occupational Employment Statistics	The Occupational Employment Statistics (OES) program produces employment and wage estimates annually for over 800 occupations. These estimates are available for the nation, for individual States, and for metropolitan and nonmetropolitan areas.	National, State and Metro Area, and metropolitan and nonmetropolitan areas		https://www.bls.gov/oes/tables.htm

Table 11. Sources of employment data (continuation).

Name	Description	Geographic Level	Temporal Factor	Contact info
U.S. Census Bureau's County Business Patterns	County Business Patterns (CBP) is an annual series that provides subnational economic data by industry. This series includes the number of establishments, employment during the week of March 12, first quarter payroll, and annual payroll.	County Zip Code	Annual	https://www.census.gov/programs-surveys/cbp/data/datasets.html
Economic Census Industry Data	Every five years, the U.S. Census Bureau collects extensive statistics about businesses that are essential to understanding the American economy. This official count, better known as the Economic Census, serves as the foundation for the measurement of U.S. businesses and their economic impact.		Every 5 years	https://www.census.gov/programs-surveys/economic-census.html

[1] In addition to the BLS, State departments of labor often can provide more detailed information for their own jurisdiction.

Productivity Measures

Productivity is a measure of the value added during the manufacturing process as it relates to the wages earned, the hours worked, and the number of people employed. It is a reflection of the education and skill level of the workforce, the application of advanced processes, and the efficient use of capital and equipment, such as production machinery and computers. Transportation infrastructure enhances productivity by allowing businesses to use their capital more efficiently. Increases in productivity by industry can result in an increase in freight shipments, even when the employment in those same industries is constant or even decreasing.

Practitioners measure productivity by showing the *value added* per unit of input (usually labor) in the production process. Using a motor vehicle plant as an example, the facility reports the value added in dollar terms reflecting the value of production taking place at the plant. Value added is the difference between the value of goods being shipped out of the plant (for example, finished pickup trucks) minus the required materials (such as paint, plastics, metal parts, electronics, and glass) to build the finished good. A source of national productivity information is the BLS multifactor productivity index: https://www.bls.gov/mfp/home.htm.

Sources of Income Data

Income data are a useful supplement to employment data and they can be a major source of inputs for the personal consumption component of freight demand.

Bureau of Economic Analysis

The U.S. Department of Commerce's Bureau of Economic Analysis (BEA) is the best source for income data. The BEA's mission is "to produce and disseminate accurate, timely, relevant, and cost effective economic accounts statistics that provide government, businesses, households, and individuals with a comprehensive, up-to-date picture of economic activity." BEA data offer the opportunity to analyze trends going back to 1969; income data can be downloaded from the BEA's website and is available at the State, metropolitan, and county levels. The BEA website also presents historic information on employment and population.

Basic profiles, explaining the growth of per capita and personal income by county, are available from the BEA Regional Facts at https://apps.bea.gov/regional/bearfacts/. This site allows users to select any State, county, or metropolitan statistical area for a profile chronicling the area's personal income using current estimates, growth rates, and a breakdown of the sources of personal income.

Personal income and per capita income data are available by county, metropolitan area, and State for the 1969-2016 period on the BEA website at https://www.bea.gov/data/economic-accounts/regional. The data on this site can only be downloaded at predefined levels of geographic detail. Additional data is available for purchase from private sources.

PERFORMANCE DATA

This section covers three publicly available data sources that deal with highway performance: the FHWA's Highway Performance Monitoring System (HPMS), the Texas Transportation Institute's Urban Mobility Report, and the National Performance Management Research Data Set (NPMRDS).

Federal Highway Administration's Highway Performance Monitoring System

The Federal Highway Administration's Highway Performance Monitoring System (HPMS) provides data that show the extent, condition, performance, use, and operating characteristics of the Nation's highways. It was developed in 1978 as a National highway transportation system database. It includes general data on all public roads, detailed data for a sample of the arterial and collector functional systems, and the full extent data on the Interstate system; HPMS also provides summary information for certain States. The HPMS collects a wide range of data, including information on route designation, functional classification, lane configurations, speed limits, traffic volumes including truck volumes, roadway geometry, and pavement condition.

The HPMS data form the basis of the analyses that support the biennial Condition and Performance Reports to Congress. These reports provide a comprehensive, factual background to support the development and evaluation of the Administration's legislative, program, and budget options. They provide the rationale for Federal-Aid Highway Program funding requests and they are used for apportioning Federal-aid funds back to the States under the Highway Authorization legislation. Both activities ultimately affect every State that contributes data to the HPMS.

The FHWA also uses the data for assessing highway system performance under their strategic planning process. Pavement condition data, congestion-related data, and traffic data used to determine fatality and injury rates are used extensively by the Administration to measure FHWA's and the State's progress in meeting the objectives in the FHWA's Performance Plan and other strategic goals.

In addition, the HPMS serves the needs of States, MPOs, local Governments, and other customers, providing data to assess highway condition, performance, air quality trends, and future investment requirements. Many States rely on traffic and travel data from the HPMS to conduct air quality analyses and determine air quality conformity. These States are now using the same analysis models used by FHWA to assess their own highway investment needs; as a result, they have an additional stake in ensuring the completeness and quality of these data.

Finally, these data are the source of a large portion of information included in FHWA's annual *Highway Statistics* and other publications. They are widely used in both the national and international arenas by other Governments, transportation professionals, and industry professionals to make decisions that impact national and local transportation systems and the transportation dependent economy.

Further information about the HPMS and its methodology can be obtained online at: https://www.fhwa.dot.gov/policyinformation/hpms.cfm.

Texas Transportation Institute's Urban Congestion Report

The *Urban Congestion Report* (UCR), published quarterly, contains data used to identify trends and examine issues related to urban congestion. The latest report includes information for 52 U.S. urban areas, and the measures presented in the report provide a basis for discussion about the significance of the mobility problems and the need for solutions.

The UCRs are available online at https://ops.fhwa.dot.gov/perf_measurement/ucr/.

National Performance Management Research Data Set

The National Performance Management Research Data Set (NPMRDS) is a monthly archive of average travel times, reported every five minutes when data is available, on the National Highway System. The travel times are based on vehicle probe-based data and separate average travel times are included for "all traffic," trucks, and passenger vehicles. Average travel times have been collected monthly since July 2013. The travel times in NPMRDS can be valuable inputs or validation data for freight modeling and forecasting.

These data provide valuable information for measuring the performance of the freight transportation system. The NPMRDS is used in calculating MAP-21 performance measures for system performance, freight, and Congestion Mitigation and Air Quality (CMAQ). NPMRDS provides the data to State Departments of Transportation (DOTs) and MPOs for planning, analysis, research, and performance measurement using a variety of data retrieval and visualization tools. Average speed and travel time data can be downloaded off-line, and users can visualize information such as congestion, trends, performance charts, buffer time indices, and planning time indices.

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CHAPTER 5. LOCAL DATA COLLECTION

This chapter provides a detailed examination on data collection opportunities to support freight planning and forecasting. The chapter is divided into three distinct sections that discuss:

- The identification of data that are needed to fill gaps in existing data sources. The refinement of available data and the collection of new data, the processing and fusion of existing and new data sources, and the maintenance of the databases are discussed.
- The collection of local freight data sources that includes establishment surveys, travel diary surveys, roadside intercept surveys, and vehicle classification counts. Key issues are discussed pertaining to freight data attributes and implementation processes.
- The emerging new sources of location freight data which provide detailed spatial and temporal data on truck movements collected using automatic vehicle location and global positioning system (GPS) tracking methods. Data sharing between public and private sectors and the funding of innovative freight data collection under the Strategic Highway Research Program (SHRP) C20 program are discussed.

Each section includes a discussion of the need for freight data collection, the common types of data collection that support freight planning and forecasting, and key issues related to costs, sample sizes, and implementation of data collection.

NEED FOR FREIGHT DATA COLLECTION

Chapter 4 provided a description of the various existing freight data sources available at national and regional levels for freight planning and forecasting applications. These included commodity origin-destination databases (such as freight analysis framework [FAF] and TRANSEARCH), modal flow databases (such as the Carload Waybill Sample), vehicle data (such as the Vehicle Inventory and Use Survey [VIUS]), and employment/industry data (such as County Business Patterns).

Although these data sources provide comprehensive information on base year conditions and can forecast freight demand, transportation supply, and economic characteristics in a region, they cannot deliver other critical data needed for freight planning/forecasting beyond the limited scope and coverage of these existing standard data sources. For example, metropolitan planning organizations (MPO) and other regional planning agencies need truck volume data on their highway network for the validation of the regional truck models. Understanding the time-of-day characteristics of truck traffic is another important data point that helps agencies plan for peak-hour interactions between passenger and freight traffic and congestion alleviation measures during peak hours.

These data elements can only be compiled from a local freight data collection effort. In addition, the data available from standard freight data sources may not be representative of the actual freight traffic characteristics in the planning region. Clearly, local data collection efforts can provide more representative and accurate data in such cases to support the freight demand analysis for planning purposes.

Collecting, compiling, and refining data and making them available for freight transportation planning can be a significant effort. A general process for collecting and consolidating data includes the following broadly defined steps:

1. **Identify and assess available data sources:** Conduct a scan of available data sources at the National, State, regional, and local level to identify gaps in the data and locate potential sources. This process generates an initial list of data sources that are candidates for new data collection.
2. **Collect and refine available data:** Parse and compile existing datasets to create a cleaned and standardized version of existing freight data.
3. **Collect new data:** Collaborate with regional freight stakeholders to collect new local freight data. This would include other State, regional, and local agencies and private industry.
4. **Process and fuse data:** Combine existing and new datasets to create an integrated freight database.
5. **Maintain data:** Create a process for maintaining the integrated freight database and updating it periodically and in a timely fashion to enhance its usefulness.

Although local freight data collection efforts require additional resources in terms of time and costs, they provide much needed data for a planning agency to conduct a comprehensive analysis of freight traffic flows in a region and to develop more accurate freight forecasts for planning applications. With any data collection initiative, agencies need to consider the costs of collecting the data and their benefits. Some critical factors that impact the time, costs, and level of effort associated with local freight data collection programs include:

- The availability and comprehensiveness of existing data.
- Type and volume of data/information needed.
- Time needed to conduct data collection.
- Desired level of accuracy and detail in the collected data.
- Types of equipment and resources required to perform data collection.
- Plan for updating and maintaining the freight database.

LOCAL FREIGHT DATA COLLECTION METHODS

Although there are a host of local freight data collection methods, this section covers the most common methods from a freight planning and forecasting application perspective. In addition to presenting the essential concepts associated with each data collection method, some key issues pertaining to costs, sample sizes, and implementation for each type of data collection, also are discussed.

Table 12 summarizes the following types of local freight data collection methods which are covered in detail in this section:

- Establishment surveys.
- Travel diary surveys.
- Roadside intercept surveys.
- Vehicle classification counts.

Table 12 provides a summary description of the objectives of each survey and identifies the sampling frame and the data collection method. The different applications that each survey can support for freight planning and modeling tasks are listed next. A summary of implementation issues related to each survey are outlined to round up key issues in local freight data collection.

Table 12. Local data collection summary.

Type	Description	Application	Implementation Issues
Establishment Surveys	Surveying owners, operators, or fleet managers of key establishments.	Trip Generation. Time of Day Analysis. Facility Type. Identification.	Type of data collection. Sample selection.
Travel Diaries	Obtaining travel diaries from truck drivers for a specified duration of time.	Truck Tours. Trip Generation. Trip Distribution. Trip Routing.	Sampling is difficult. Potential for bias. Low response rates. Expensive method.
Roadside Intercept Surveys	Intercepting trucks on the road, and interviewing truck drivers to get information on their truck trip characteristics.	Origin-Destination (O-D) Flow Matrix. Trip Distribution. Payload Factors. Tonnage Distribution. Empty and "Through" truck factors. Market Research.	Potential for bias due to limited locations. Traffic disruption and safety risks. Capture of movements outside of internal-internal movements.
Vehicle Classification Counts	Counting traffic for each vehicle class (based on a vehicle classification system) for a specified duration of time at key locations on the highway network.	Calibration/Validation. Time of Day analysis. Trip Generation. Corridor Utilization.	Site selection. Data variability.

Also included later in this chapter is a discussion of new data collection techniques such as passive data collection from GPS tracking of trucks and cargo, and data on truck travel times.

Establishment Surveys

Introduction

Surveying establishments engaged in freight activity is an important element of a local freight data collection effort in a region, since they generate a large portion of local and long-haul (internal-external and external-internal) freight flows. This data collection method involves surveying owners, operators, or fleet managers of key establishments, which includes manufacturing facilities, warehouses, retail distribution centers, truck terminals, and transload facilities.

These surveys may include terminal gateway facilities like seaports, airports, and intermodal yards. However, establishment surveys have limited use for terminal gateways. They can provide information on economic characteristics of the facility (such as number of employees), but the increased truck traffic volumes and patterns associated with terminal facilities make terminal gateway intercept surveys the better choice for collecting information on truck traffic characteristics.

A key challenge with these surveys is identifying and reaching the right person in the organization to respond to the survey. The use of business directories, such as Dun & Bradstreet or InfoUSA, may be useful in identifying personnel contacts that can provide the required information. The direct use of a business directory to obtain industry employment information and location information (i.e., latitude and longitude) for firms that can be summarized by geographic units (i.e., traffic analysis zones) is discussed later in this chapter.

The primary methods of conducting establishment surveys include telephone interviews, mail-out/mail-back surveys, e-mail surveys, and online surveys, which may be done in combination. A traditional recruitment method via a telephone interview is often used to overcome the difficulty of identifying the right person in the establishment to fill out the survey. Establishment surveys can be used to collect comprehensive information regarding economic, land use, and modal freight (e.g., trucking, rail) activity characteristics of freight facilities, which can provide key inputs for freight modeling and planning applications.

Specific data attributes that can be collected include:

- Facility hours of operation.
- Number of employees.
- Facility land area.
- Fleet size.
- Fleet ownership.
- Types of trucks in the fleet (e.g., straight, tractor-trailers).
- Commodities handled.
- Average payloads by commodity and type of truck.
- Types and share of trucking services (e.g., parcel, truckload, and less than truckload).
- Average daily inbound and outbound truck shipments.
- Average trip lengths.

- Truck trip-chaining activity.
- Truck origin-destination (O-D) distribution patterns.
- Types of facilities used.

In addition, establishment surveys can help agencies understand how key transportation performance variables such as transportation costs, travel times, reliability, highway regulations, and roadway closures impact shipment decisions.

Applications

The following are key freight forecasting and planning applications for the data collected from establishment surveys.

Trip Generation: Data collected from establishment surveys on the number of employees, land area, and average daily truck trip productions and attractions can be used to develop truck trip generation estimates. These data elements can serve as inputs to the two common approaches for trip generation, which include trip generation rates and regression equations.

Establishment surveys may be a feasible option for trip generation data, since they can collect daily trucking activity information for the facility at a reasonable level of accuracy using limited resources, compared to conducting traffic counts that are more expensive. In addition to providing data estimates for trip generation, establishment surveys can collect economic data on future employment and labor productivity for the facility, which are key inputs for facility freight forecasting and planning.

Winston-Salem Urban Area established analytic approaches describing how elements of the freight transportation system operate and perform. The project began with identifying freight model design and future data collection needs for the region to support development of a tour-based truck model. An extensive review of commonly available data sources was done to locate freight facilities. This was followed by a detailed establishment survey to collect more information on those facilities. This allowed the analysis of truck trip generation rates against variables such as the number of employees, building square footage, and the number of loading bays. The results set the groundwork for developing a tour-based freight model targeted at improving freight mobility within the region.

Other Applications: Other key applications of the data collected from establishment surveys include the following:

- **Time-of-day analysis to measure variations in trucking activity at a facility by time of day—**For site/facility planning purposes, it is useful to understand time-of-day interactions between trucks and automobiles, and to plan for the efficient movement of freight during peak periods.

- **Analysis of the types of facilities used by trucks generated by a facility across different commodity groups—**This can be useful for developing trip distribution models, such as truck traffic disaggregation models, and land use planning associated with large freight generators such as seaports. Establishment surveys of trucking terminals also can yield useful data on the types of facilities used by type of carrier (truckload, less than truckload [LTL], or private) to validate trip distribution patterns based on truck trips by carrier type.

Implementation Issues

Type of Data Collection: Deciding on the type of the recruitment approach and method of survey data collection (telephone, mail-out/mail-back, or combined telephone and mail) is an important decision in the implementation of establishment surveys. Each of these methods has advantages and limitations associated with the ability to reach the right person in the establishment to fill out the survey, the type and volume of data collected, and the time and costs associated with the data collection effort.

Historically, mail surveys have been the most commonly used method for establishment surveys, due to the relative ease of implementation compared to telephone or combined telephone and mail surveys. The investment costs and personnel requirements associated with mail surveys also are typically the lowest. However, mail-out/mail-back surveys have many limitations including their low response rates and the inability to clarify responses to specific questions.

Telephone surveys have relatively higher response rates compared to mail-out/mail-back surveys. However, they may be less effective at gathering comprehensive trucking activity information, since identifying and reporting specific trip details about all shipment types can be prohibitive in a telephone conversation. Telephone interviews also require the availability of accurate contact information on potential interviewees (owners, operators, or fleet managers), and compiling these data can be a time-consuming and costly undertaking.

Combined telephone and mail surveys offer higher response rates, since the establishments are contacted by phone ahead of time and notified about the mail survey. However, this survey approach typically has the highest cost of implementation. Finally, online freight surveys have become more common and can be provided as an additional option to respondents. Such a survey allows respondents to respond at their own time and pace and minimizes processing of the dataset.

Many of the questions asked in these surveys are similar. Several jurisdictions or survey locations may wish to coordinate their efforts to reduce costs while increasing statistical accuracy.

Table 13 presents the advantages and limitations associated with each type of data collection based on survey implementation, level of investment and cost, statistical reliability, data attributes, and geographic coverage.

Sample Selection: Sample selection is an important element in the design of an establishment survey data collection effort. The larger the sample size, the more reliable and comprehensive the data collection is. However, it would be practically impossible and cost prohibitive to survey the entirety of establishments located in a region. Developing appropriate sampling frames is critical not only for minimizing the overall cost of the data collection effort, but also for ensuring that the sample surveys provide unbiased and reliable data on the economic, land use, and freight activity characteristics of establishments in the region.

Table 13. Advantages and limitations of various establishment survey methods.

Method	Advantages	Limitations
Mail-Out/ Mail-Back Survey	• Ease of implementation. • Low data collection costs, and minimal personnel requirement. • Generally good information and data detail from survey respondents.	• Low response rates. • Limited ability to clarify responses to specific questions. • Difficulty finding the appropriate person at the establishment to complete the survey. • Need to enter data into a database.
Telephone Survey	• Ease of implementation. • Quicker turnaround compared to mail-out/mail-back surveys. • Low data collection costs. • Ability to clarify responses. • Better success rates for follow-up surveys compared to mail-out/ mail-back surveys.	• Compiling phone numbers and contact person information can be difficult and time-consuming. • Surveys can only be conducted during normal business hours. • Higher personnel requirement compared to mail-out/mail-back surveys. • Need to enter data into a database.
Combined Telephone and Mail Surveys	• Quicker turnaround than mail-out/ mail-back surveys. • Improved ability to clarify intent of data collection, and explain questions, leading to better detail and accuracy in collected data. • Relatively higher response rates compared to mail-out/mail-back surveys.	• Compiling phone numbers and contact person information can be difficult and time-consuming. • Higher personnel requirement compared to mail-out/mail-back surveys.
Online surveys	• Quickest turnaround. • Allows respondents to schedule their own responses at a convenient date and time.	• Difficult to provide clarity on survey questions. May require multiple questions on the same subject to determine true response. • Difficult to eliminate biases in responses. • Difficult to control responses and develop expansion factors.

There is no definitive methodology for arriving at the proper sample size. In the case of establishment surveys, the primary factor impacting sample size is the method of data collection, since each method is associated with different response rates. For example, in the case of a mail-out/mail-back survey, the generally low response rates may require the use of a broader sampling frame compared to a telephone interview survey with relatively higher response rates. In the case of online surveys, it is more difficult to control who is responding to the survey and multiple responses may come from the same establishment. Other factors that will impact the sample size are the costs of data collection and the reliability and the accuracy of the available contact information.

In the case of establishment surveys of freight facilities such as manufacturing plants, warehouses, and distribution centers, the sampling approach usually involves selecting establishments based on their employment size or land area. Standard privately-owned data sources, such as Dun & Bradstreet or InfoUSA, are available for purchase and provide the universal listing of establishments in a region for sampling, along with their economic characteristics. Additionally, there may also be publicly available data compiled by State economic development departments, MPOs, or organizations such as port authorities that include major freight establishments in a region and can be used to draw the sample.

In the case of establishment surveys of trucking terminals, the sampling strategy would typically depend on trucking characteristics in the region. For example, a very high level of local distribution activity in a large metropolitan area would suggest a sampling approach that focuses on capturing a larger fraction of motor carrier establishments involved in short-haul local distribution activity. This would allow an agency to collect a statistically reliable sample and conduct unbiased analysis of trucking activity in a metropolitan area.

Travel Diary Surveys

Introduction

Travel diary surveys are a useful method of data collection, particularly for understanding internal-internal (local) truck trip activity in an urban area. The basic approach of data collection involves selecting a representative sample of trucks operating in the region, and obtaining travel diaries from truck drivers for a certain time duration. The usual period for data collection is 24 hours; however, depending on the willingness of drivers to complete trip diaries, the surveys can be conducted for time periods extending more than a day (typically, three days or a week).

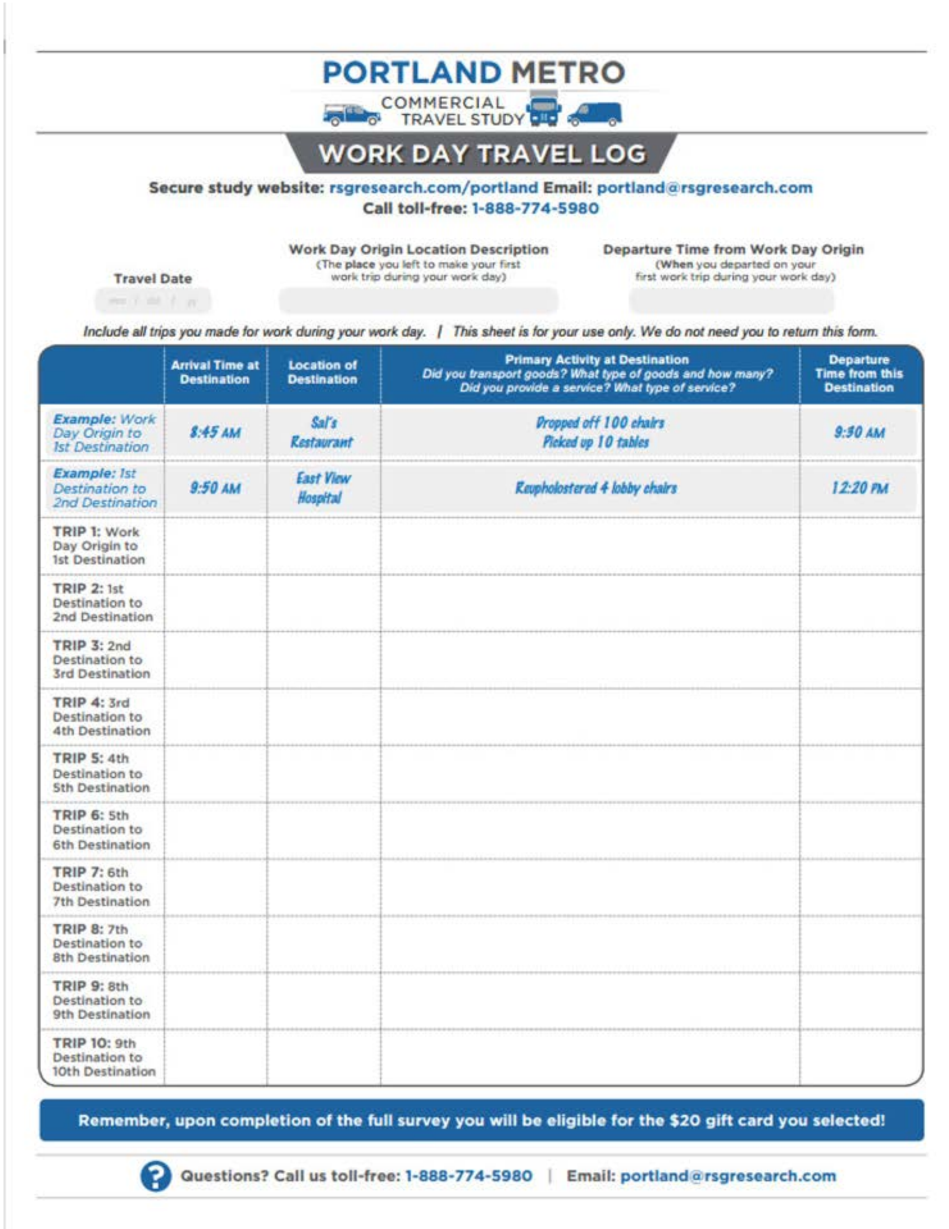
Table 14. Advantages and limitations of travel diaries.

Method	Advantages	Limitations
Travel Diary Survey	Can ask questions concerning the truck, its contents and the purpose of the stop.	Expensive to implement and expand.
	Can determine how trips between stops are linked into tours.	Driver cannot be expected to know details about the stop (e.g., square footage at stop, number of employees, etc.)
	Can provide insights into the duration at a stop and times traveled between stops.	Difficult to contact drivers not registered in the study area, but might stop in the study area.
		Cannot capture information about trucks that only pass through study area.
	Collection of comprehensive truck trip information on O-D, routing patterns, commodities, shipment sizes, truck types, and facilities used.	Less effective for collecting information on internal-internal truck traffic characteristics because of the limitations in the number of sites and the complexities in distribution patterns of internal-internal trips.

Traditionally, surveyors provide travel diaries through forms completed manually by the driver, listing the truck trip characteristics for the period of the survey. Drivers are asked to record information on the truck trip regarding:

- Origin.
- Destination.
- Trip mileage.
- Routing.
- Travel time.
- Trip time of day.
- Commodity hauled.
- Size of shipment.
- Truck type.
- Land use and activity at the trip end including pickup, delivery, refueling, or rest area.

Additionally, truck drivers may be asked to report their type of carrier operation (truckload, LTL, or private), in cases where this information cannot be deduced from the source data. The costs of recruiting participants for travel diary surveys can be considerably reduced if the recruitment process is conducted during an Establishment Survey.



PORTLAND METRO
COMMERCIAL TRAVEL STUDY

WORK DAY TRAVEL LOG

Secure study website: rsgresearch.com/portland Email: portland@rsgresearch.com
Call toll-free: 1-888-774-5980

Travel Date

Work Day Origin Location Description (The place you left to make your first work trip during your work day)

Departure Time from Work Day Origin (When you departed on your first work trip during your work day)

Include all trips you made for work during your work day. | This sheet is for your use only. We do not need you to return this form.

	Arrival Time at Destination	Location of Destination	Primary Activity at Destination *Did you transport goods? What type of goods and how many? Did you provide a service? What type of service?*	Departure Time from this Destination
Example: Work Day Origin to 1st Destination	8:45 AM	Sal's Restaurant	Dropped off 100 chairs Picked up 10 tables	9:30 AM
Example: 1st Destination to 2nd Destination	9:50 AM	East View Hospital	Reupholstered 4 lobby chairs	12:20 PM
TRIP 1: Work Day Origin to 1st Destination				
TRIP 2: 1st Destination to 2nd Destination				
TRIP 3: 2nd Destination to 3rd Destination				
TRIP 4: 3rd Destination to 4th Destination				
TRIP 5: 4th Destination to 5th Destination				
TRIP 6: 5th Destination to 6th Destination				
TRIP 7: 6th Destination to 7th Destination				
TRIP 8: 7th Destination to 8th Destination				
TRIP 9: 8th Destination to 9th Destination				
TRIP 10: 9th Destination to 10th Destination				

Remember, upon completion of the full survey you will be eligible for the $20 gift card you selected!

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Figure 7. Sample one pager. Example work day travel log.
(Source: Portland Metro.)

With advancements in technology, travel diary surveys are commonly done by providing a smartphone or tablet application to truck drivers. This has simplified the process from the paper logs, since drivers don't need to record time and location data that are already captured from the GPS receivers within their electronic device. Users can enter information that cannot be determined passively and pertains to commodity hauled, shipment size, and activity at the trip end.

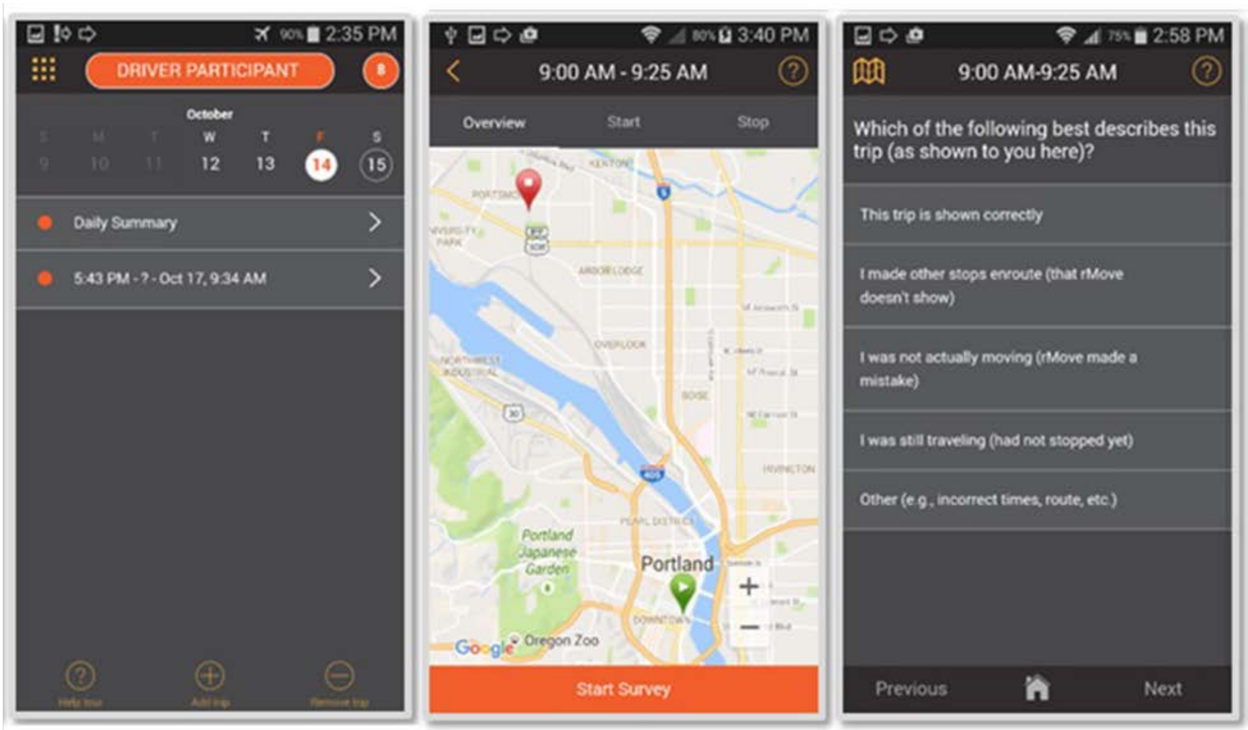

Figure 8. Screenshot. Example of a survey smartphone application.
(Source: Portland Metro.)

Some companies may share GPS data from their fleet. GPS-based data collection for a travel diary survey can be combined with other data sources and methods of data collection. For example, origin, destination, and routing information received from GPS receivers can be used to validate and improve the information provided by truck drivers in manually completed travel diaries. Also, combining GPS truck trip information with land use data from geographic information systems can yield useful information on truck activity characteristics at trip ends.

Installing GPS units in trucks to supplement travel diaries is separate from using GPS data and other locational and timestamped data that are available as part of trucking operations such as fleet management or automatic vehicle location. Several vendors (e.g., American Transportation (formerly Trucking) Research Institute (ATRI), StreetLight Data, and INRIX) obtain and provide these data which are anonymized to protect proprietary information. Business stops may need to be inferred, and it is difficult to obtain land use information for these inferred stops.

Applications

Some key freight forecasting and planning applications of the data collected from travel diary surveys are listed below. They include the inference of truck tours, the use of diary surveys in trip generation and trip distribution, and can assess variation in truck routing patterns.

Truck Tours: Travel diary surveys are particularly useful for understanding internal-internal local truck trip activity in a region. The most important application is analyzing truck tours by linking truck tours into chains of truck trips to develop more robust and accurate urban truck travel demand models. Travel diaries capture the entire trip-making activity of each individual truck over a 24-hour period, which can be used to trace the occurrence of trip chaining. For example, a truck tour is developed starting from a trip diary entry for a trip starting from the home base to a pickup location, proceeding to a drop-off location, and then proceeding to another drop-off location. Similar trips and tours are common in urban areas, particularly for local distribution trips that are related to retail activity. Truck tours inferred from travel diaries can be coupled with information on commodity type, carrier type, and land use and activity at trip ends to understand tour distribution patterns and provide inputs to develop activity-based truck travel demand models.

Trip Generation: Travel dairies are not the preferred source to develop truck trips generation models. While travel diaries can provide information on the shipment being carried in specific trucks, the drivers may not be aware of key information needed to estimate trip generation rates. For example, while a truck driver preparing a travel diary may know the contents and size of a shipment, that driver is unlikely to know the characteristics of the locations where the truck is stopping. Establishment surveys are a better source to develop those truck trip generation rates. In addition, the surveyed establishments can report both on trucks registered to the establishment and trucks registered elsewhere.

However, trip diaries may be the only source of information on trips made to locations that are not included in the establishment survey, such as residences. In those cases, the explanatory data available may be limited to the responses in the diary.

Trip Distribution: The trip diaries contain information about the previous and next stop of the truck and the travel impedance between those stops that cannot be derived from establishment surveys. This information is useful for modeling truck trip distribution. The distribution pattern of freight carrying trucks is different than the distribution pattern of non-freight trucks. Travel diaries cannot determine the distribution pattern of both non-freight and freight trucks, but they may be used to determine details of the distribution of freight shipments being carried in those trucks. The diary may not provide information about the ultimate origin of the goods being carried, but it provides the origin of the truck on the supply chain of that cargo.

Traffic Routing: Travel diaries may record the general routes taken by trucks for each truck trip between O-D pairs. These data can be used to determine truck traffic routing patterns in the region for the validation of traffic assignment procedures. GPS-based travel diaries provide accurate and real-time truck routing information, which serve as critical inputs for the analysis of routing pattern variations by time of day. For example, these patterns can be analyzed to determine how congestion during peak hours may impact truck routing patterns during a typical day compared to the nighttime.

Implementation Issues

Sampling Frames: The selection of an appropriate sampling frame is an important element in the design of travel diary surveys. Vehicle registration databases are commonly used data sources for developing a sampling frame that contains the listing of all the trucks registered in a region. These databases are typically maintained by State Departments of Motor Vehicles (DMV). The approach used to sample the population plays a critical role in determining the uses of the data gathered for planning and modeling applications. For example, if a survey provides data to better understand truck trip-chaining activity in the region, then the sampling approach should consider selecting a larger fraction of trucks primarily performing short-haul local distribution activity compared to long-haul shipments.

Random or systematic sampling techniques are not optimal for selecting sampling frames for travel diary surveys because the sample tends to have the same distribution of trucks as in the population of trucks. Stratified sampling is the best approach and involves segmenting trucks in the population and selecting samples from each stratum to develop the sampling frame. Vehicle registration databases may provide average trip length information for each individual truck record, which can be used to stratify trucks based on short- and long-haul trucking activity. The sampling frame can then be developed by selecting a larger fraction of trucks performing short-haul trucking movements. Annual vehicle miles traveled (VMT) data for each truck record may be another potential parameter to support stratified sampling although it is not a very good indicator of short-haul versus long-haul trucking activity.

Data Limitations: Some key limitations associated with data collected from travel diary surveys include the following:

- Contacting and sampling the right respondent can be difficult, especially in cases where there is lack of good address and telephone information on points of contact for trucks operating in the region.

- The use of vehicle registration databases for the surveys may produce biased results in cases where there is a significant fraction of trucking activity associated with trucks not registered within the region. In this case, the travel diary surveys may potentially underestimate the total trucking activity in the region.

- A key issue associated with travel diary surveys is low response rates. Truck owners are often not willing to participate in the survey due to confidentiality issues related to sharing travel and customer information and due to interruptions to their normal work schedule.

- Travel diary surveys using GPS receivers are relatively more expensive to implement and there is a risk of equipment failure in these surveys.

Roadside Intercept Surveys

Introduction

Roadside intercept surveys involve intercepting trucks on the road and interviewing truck drivers to get information on their truck trip characteristics. Interviewers complete survey questionnaires based on information provided by the driver in a personal interview. Some jurisdictions no longer allow roadway intercept surveys due to safety concerns. Typically, the interviewer makes visual observation of the vehicle to gather information about its configuration and number of axles. Steps involved in developing and implementing a roadside intercept survey, include:

- Preparation of the survey questionnaire.
- Site selection and site preparation.
- Recruiting and training of survey personnel.
- The identification of a sampling frame.
- Survey administration.
- Survey data synthesis and analyses.

Depending on the types of freight modeling and planning applications, roadside intercept surveys can gather comprehensive information about truck travel characteristics in a region. The key data attributes collected through roadside interviews include:

- O-D locations (State, city, zip code).
- Routing patterns.
- Type of commodity.
- Vehicle and cargo weight.
- Shipper and receiver information (business name, contact, type of facility, etc.).
- Trucking company information (business name, contact, type of carrier—truckload, LTL, or private).
- Type of truck (number of axles and number of units).

The locations for conducting roadside intercept surveys depend on the O-D truck travel patterns under analysis. To gather truck trip characteristics of internal-external, external-internal, and external-external (through) trips, the most common approach is to conduct surveys at external cordon locations. External cordons are the highway gateways used by trucks to enter and exit the study area. Collecting roadside intercept surveys within urban areas for internal-internal trips can be prohibitive, because surveys need to be conducted at many locations to capture the complex internal distribution patterns of trucks. Traffic congestion and/or limited space availability at survey sites present additional challenges. Some common locations for conducting roadside intercept surveys include weigh stations, toll plazas, and border crossing locations.

Terminal gateway surveys are a special class of roadside intercept surveys, where trucks entering and exiting terminal gateway facilities (seaports, airports, and intermodal rail yards) are intercepted and surveyed to get information on:

- O-D locations.
- Routing.
- Commodities carried.
- Payloads.
- Truck types.
- Types of carriers.
- O-D facilities used by trucks in terminal gateways.

Roadside intercept surveys generally focus on "last stop-next stop" origins and destinations since questions involving multiple stops (trip-chaining activity) can be confusing to the driver and may yield unreliable data. This can be a potential limitation if the last stop-next stop of the surveyed trip involves activities that are not related to goods movement such as fueling and rest areas.

Applications of Roadside Intercept Survey

Data collected from roadside intercept surveys are useful for freight modeling and planning applications, which are discussed in the following sections.

Origin-Destination Freight Flow Matrix: A primary application of roadside intercept surveys is the development of O-D freight flow matrices for a region. Depending on the extent of data available and the level of accuracy of the geocoding process for the O-D locations, a traffic analysis zone (TAZ) level O-D freight flow matrix can be developed from the survey data. However, only the external gateway surveys offer the ability to develop accurate O-D matrices, since surveys conducted at internal locations are typically inadequate for developing a comprehensive O-D matrix and incorporating all the possible O-D flow combinations in a region. The O-D matrix developed from external gateway surveys contains truck freight flows between external cordons and internal regions (TAZs or districts) and can be delineated for commodity flows (in tons) by trucking submodes (truckload, LTL, and private) or truck trips by truck class. These O-D matrices serve as key inputs in the development of external truck models for urban areas.

Commodity-specific flows from these matrices can be used to validate the TAZ-level disaggregation procedures in existing urban truck models for trips produced and attracted. Roadside intercepts can only provide information on the trucks being surveyed. They are typically accompanied by counts at that location that are used to expand the survey responses, but this expansion cannot capture locations that were not surveyed. Deciding that sufficient roadside intercepts were collected to develop an O-D table is a matter of judgment. Roadside intercepts may be more useful in providing information about a facility, but do not provide information about the locations discussed in the surveys.

Trip Distribution: Truck O-D information collected from terminal gateway surveys are essential inputs for developing truck trip distribution tables for terminal facilities. These tables can be developed by type of commodity and/or truck class to understand the variations in terminal gateway distributions as a function of these parameters.

Payload Factors: Roadside intercept surveys collect information on the type of commodity, weight of cargo, and type of truck that can be used to develop weighted average payload factors by commodity group and truck classes. These factors can be used in the development of commodity-based urban truck models (which involve conversion of commodity flows to equivalent truck trips by each truck class) or the validation of payload factors in existing truck models to improve the accuracy of predicted truck trips.

Commodity Tonnage Distribution to Truck Classes: The type of commodity, weight of cargo, and type of truck information collected from the surveys can be used to develop tonnage distributions for each commodity group carried by each truck class at these locations. This information is a key input in commodity-based truck models to distribute total commodity flows to each truck class that can predict truck trips by truck classes.

Table 15 outlines in some detail the advantages and limitations of intercept surveys at roadside locations or terminal gateways.

Table 15. Advantages and limitations of roadside surveys and terminal gateways.

Method	Advantages	Limitations
Roadside Surveys or Terminal Gateways	Offer the best statistical control and reliability, since the sample is drawn from sites with known traffic characteristics.	There are only a limited number of locations where intercept surveys may be implemented in a region. This can lead to sampling bias in the truck travel characteristics determined from the survey.
	Higher response rates compared to mail or telephone surveys, due to direct one-on-one interview with the driver.	Potential traffic disruption, especially when surveys are conducted by roadside pull-offs.
	Provide a good statistical representation of trucks entering, exiting, and passing through the study area.	Potential risks for survey personnel include safety risks from traffic and security risks from direct contact with interviewees.
	Low data collection costs if the survey is managed and administered properly.	Method only captures truck traffic characteristics of trucks passing through survey sites.
	Collection of comprehensive truck trip information on O-D, routing patterns, commodities, shipment sizes, truck types, and facilities used.	Less effective for collecting information on internal-internal truck traffic characteristics because of the limitations in the number of sites and the complexities in distribution patterns of internal-internal trips.

Empty and Through Truck Factors: Empty truck trip fractions at external cordons are key inputs in commodity-based urban truck models. Collecting through truck traffic information is a key requirement for developing robust truck models. The fraction of total trips that are through trips at each external cordon is key to establishing the through truck traffic distributions.

Market Research: Roadside intercept surveys can be used for market research and have been applied successfully in many studies, particularly related to cross-border movements. Using intercept surveys at border crossing locations, information can be collected on major shippers and receivers involved in cross-border trade, as well as major carriers performing cross-border shipping operations.

Implementation Issues

Sampling Rates: Because of the impracticality of intercepting all the trucks passing through the survey site, sampling rates are typically developed to select a sample of the total truck traffic. These rates can vary based on the total truck traffic volumes at the location and the type of truck.

Sampling rates also can depend on the processing rate of surveyed trucks at the site, which is a function of the number of interviewers and slot spaces available at the survey site. Typically, roadside surveys at the site are accompanied by vehicle classification counts determine total trucks passing through the location for expanding the survey sample data.

Three questions need to be answered when performing sampling analyses for roadside intercept surveys:

1. **Where to sample?** Selecting the sites for performing surveys. Key parameters that help answer this question include the major locations for entry and exit of truck traffic in a region including locations of existing truck stop sites such as weigh stations, rest areas, toll plazas, and border crossing.

2. **Who to sample?** Selecting which trucks to survey and in what quantity. Key parameters that help answer this question include the types of trucks passing through the site and the volume of traffic by each truck type.

3. **When to sample?** Selecting the day of week and seasons to account for weekly and seasonal variations in truck traffic patterns. Key parameters that help answer this question include the volume of truck traffic in the region by day of week and seasonal truck traffic volumes. These data can be typically collected from weigh-in-motion (WIM) sites and permanent traffic recorders.

There are no specific guidelines for arriving at a sampling frame for the surveys, since each region has unique truck traffic characteristics in terms of total traffic volumes, types of truck, site characteristics, time-of-day truck traffic distributions, and weekly and seasonal traffic variations.

Personnel Training and Other Operational Issues: Recruiting and training personnel to conduct interviews of truck drivers is a critical component in the design and implementation of a roadside intercept survey program. There are, however, many data collection firms specializing in roadside intercept surveys that can be hired to conduct roadside interviews. A less expensive approach is to recruit personnel from local organizations and/or volunteer groups (community service clubs) comprised of individuals with good knowledge of local roads and understanding of general traffic patterns in the region. Typical components of personnel training for roadside intercept surveys include:

- Instructions in personal interviewing techniques.
- Accurate identification of different truck and tractor-trailer combinations (along with number of axles).
- Procedures and requirements for ensuring personal and third-party safety at the survey site.

Other operational elements to consider include the provision of accessories for data collection, including clipboards and pens, electronic tablets, smartphone apps, reflective safety vests, headlamps, hats for survey personnel, and equipment for each site with survey crew signs and traffic cones. Additionally, it is advisable to deploy an enforcement officer at the site to ensure the safety of survey personnel. Effective direction of selected trucks to the survey site helps ensure a high degree of compliance and can lead to high response rates. Electronic data collection may require additional supervision to monitor the electronic devices provided to surveyors. If electronic data collection by the surveyors replaces data entry, additional training may be necessary to ensure that surveyors will record the information properly.

Vehicle Classification Counts

Introduction

Collecting vehicle classification counts is a common local data collection method, which involves counting traffic for each vehicle class (based on a vehicle classification system) for a certain duration of time at key locations on the highway network. Typically, the counts are collected during weekdays over two or more days to get average weekday traffic volumes at the count location. Collecting counts by vehicle class is important to differentiate between automobile and truck traffic volumes and to analyze truck traffic volumes by truck type. The applications of vehicle classification counts are discussed in detail in a subsequent section.

The resources required to support a comprehensive classification program often exceed the resources available to support freight data collection. Agencies collect this information to support infrastructure design, maintenance, or safety analyses. In most cases, classification count programs will not meet all freight-related needs, but freight planners should expect that classification counts are available for some locations when deciding on these programs.

The general methods of collecting vehicle classification counts are:

1. **Manual Observation—**Manual counting procedures involve a trained observer collecting vehicle classification counts at a location based on direct observation of vehicles. This procedure is generally used for short durations of count data collection (for example, peak hour), and in cases where available resources do not justify the use of automated counting equipment. Typical equipment used in recording observed traffic includes tally sheets, mechanical count boards, and electronic count boards.

2. **Short Duration Count Station—**A site that uses an automated traffic counter and is recording traffic distribution and variation of traffic flow for a specified period (less than 365 days per calendar year). The counter may be moved to accommodate count locations. The goal of a short-duration count station is to collect data that can be adjusted by factoring and creating an annual average daily traffic (AADT) number that representing a typical traffic volume number any time or day of the year. Short-duration count stations typically are defined as stations where 24 hours, 48 hours, or one week of data are collected.

3. **Continuous Count Station—**A site that uses an automated traffic counter and is recording traffic distribution and variation of traffic flow by hour of the day, day of the week, and/or month of the year. It is recording the data 24 hours a day, 7 days a week. The goal of a continuous count site is to capture data for 365 days of the year.

4. **Vehicle Classification Counters—**Vehicle classification system separates vehicles into categories depending on whether they carry passengers or commodities. Non-passenger vehicles are further subdivided by the number of axles and the number of units, including both power and trailer units. Axle-based automatic vehicle classifiers rely on an algorithm to interpret axle spacing information and correctly classify vehicles into these classes.

5. **Weigh In Motion (WIM)—**Gross-vehicle weight of a highway vehicle is due only to the local force of gravity acting upon the composite mass of all connected vehicle components, and is distributed among the tires of the vehicle through connectors such as springs, motion dampers, and hinges. Highway WIM systems are capable of estimating the gross weight of a vehicle as well as the portion of this weight, called load, that is carried by the tires of each wheel assembly, axle, and axle group on the vehicle.

Table 16 identifies different vehicle detection technologies, presents how the technology is used to infer vehicle characteristics, and summarizes the types of outputs of each method that can provide data on truck and freight movements.

Table 16. Technology definition and operations of vehicle classification methods.

Technology	Definition and Operation Method	Vehicle Classification Detecting Methods
Video Image Processing	Video image processor systems detect vehicles by interpreting video images and converting signals into traffic flow data. This method can be trained to recognize vehicles' classification and identification based on the digital imagery that is presented.	Analysis of video images: Vehicle classification by length, edges, and combinations of features and sizes.
Laser Scanner/ LiDAR	A transmitted pulsed or continuous light which is used to image objects, utilized three dimensional (3D) data which extracts road data from classification.	Creation of 3D images: Vehicle classification by length, edges, shapes, features, and sizes.
License Plate Recognition	Captures photographic video or images of license plates, which are processed through a series of algorithms to capture and identify the license plate image.	Analysis of license plates photos or images: Vehicle classification based on registration information.
Transponders	Detects vehicles and collect data when they pass through transponder stations.	Analysis of vehicle registration data: Vehicle classification based on registration information.
Inductive Loop	A sensor can detect vehicle passage and presence. There are two basic undercarriage loop classifier technologies. One uses the "signature" from existing loops to determine classification by matching the shape of that loop to expected profiles. The other uses specific types of loops to detect changes in inductance associated with wheels, and uses that information to detect and measure axles.	Analysis of complex information: Vehicle classification by length, axles, and loop signatures.

Table 16. Technology definition and operations of vehicle classification methods (continuation).

Technology	Definition and Operation Method	Vehicle Classification Detecting Methods
Weigh-in-Motion	The technology used records axle weights and gross vehicle weights as vehicles drive over a measurement site. Traffic loading data collected by WIM include wheel loads, axle loads, and gross vehicle weights (GVW). In addition, WIM devices collect traffic volume, axle spacing, vehicle classification, and speed data. Frequently used WIM sensors include bending plate, load cell, quartz piezo, polymer piezo, and the strain gauge strip sensor. Motor vehicle enforcement officers use truck axle load data to screen and identify vehicles that violate weight limits. Highway planners and engineers use WIM data to develop summary statistics for freight movement studies, and pavement and bridge design.	Vehicle classification by number of axles and weight.
Microwave Doppler	The constant frequency signal (with respect to time) allows vehicle speed to be measured using the Doppler principle. The frequency of the received signal is decreased by a vehicle moving away from the radar and increased by a vehicle moving toward the radar. Vehicle passage or count is denoted by the presence of the frequency shift.	Vehicle classification by length.
Microwave Radar	Vehicle detection devices transmit electromagnetic energy from an antenna towards vehicles traveling the roadway. When a vehicle passes through the antenna beam, a portion of the transmitted energy is reflected back towards the antenna. The energy enters a receiver where the detection is made and traffic flow data, such as volume, speed, and vehicle length are calculated.	Vehicle classification by length.
Magnetometer (two-axis fluxgate magnetometer)	Passive devices that detect the presence of a ferrous metal object through the perturbation (known as a magnetic anomaly) that it causes in the Earth's magnetic field. Its output is connected to an electronics unit.	Vehicle classification by length.

Table 16. Technology definition and operations of vehicle classification methods (continuation).

Technology	Definition and Operation Method	Vehicle Classification Detecting Methods
Piezo/ Quartz Sensor	An axle detection sensor embedded in the roadway produces a signal when an axle/tire comes across it.	Vehicle classification by number of axles.
Passive infrared	A device whose infrared-sensitive element detects and converts the reflected and emitted energy from vehicles, road surfaces, and other objects into electrical signals.	Vehicle classification by number of axles.
Magnetic Detector (induction or search coil magnetometer)	A device that detects changes in the Earth's magnetic field caused by the movement of a ferrous metal vehicle in or near its detection area. It is placed under or in the roadway to detect the passage of a vehicle over the sensor. These sensors generally detect only moving vehicles. Their output is connected to an electronics unit.	Cannot classify vehicles.
Air switch/ pneumatic tube	A tube installed perpendicular to traffic, in which a burst of air pressure produces an electrical signal as a vehicle's tires pass over the tube.	Cannot classify vehicles.
Ultrasonic	Transmits pressure waves of sound energy at a frequency between 25 and 50 kHz, which is above the human audible range. Most ultrasonic sensors operate with pulse waveforms and provide vehicle count, presence, and occupancy information.	Cannot classify vehicles.
Passive Acoustic Array Sensors	Measures vehicle passage, presence, and speed by detecting acoustic energy or audible sounds produced by vehicular traffic from a variety of sources within each vehicle and from the interaction of a vehicle's tires with the road.	Cannot classify vehicles.

(Source: SHRP2 C20 and Florida DOT.)

The vehicle classification system used for the count program can vary depending on the need and the method used for counting vehicles.

- Classifying vehicles by the number of axles is the most basic vehicle classification scheme. However, this limits the applications for freight planning; for example, this method does not differentiate between automobiles and two-axle trucks, which is an important piece of information for freight planning applications in urban areas.

- The Federal Highway Administration (FHWA) 13-group vehicle classification system is a common and efficient scheme for classifying vehicles (trucks are classified based on the number of axles and units). This system was originally adopted to support infrastructure planning (e.g., pavement design) and the data reported may require transformation to support freight/truck planning. The 13-group FHWA system is described in detail at the following website: https://www.fhwa.dot.gov/policyinformation/tmguide/#chap1.

- Some data collection methods, such as pneumatic tubes, are based on counting the number of axles and cannot classify vehicles using the FHWA 13-group system. The key to classifying vehicles in count programs and using them for freight planning applications is to understand how the different classification schemes relate to one another. One example is the ability to translate length-based classification data from loop detectors to axle-based classification.

For more information on traffic monitoring programs, the analyst can visit: https://www.fhwa.dot.gov/policyinformation/tmguide/

Applications of Vehicle Classification Counts

Vehicle classification counts are useful in freight planning and forecasting. Some of the most important applications are for:

- Model calibration and validation purposes.
- Analysis of truck flows by time of day.
- As an input to trip generation.
- Helping identify major freight corridors and access routes at a regional level.

Each of these applications is briefly described in this section.

Model Calibration: One of the most important applications of vehicle classification counts is model calibration. Truck counts by truck type can be used to calibrate input O-D trip tables of regional truck models using an origin-destination matrix estimation (ODME) process. To best meet the needs of this application, the collected counts should provide good geographic coverage of key truck traffic locations in the region. Ideally, a large sample is available with counts on the major highway network links which carry the most “shortest/least-cost paths” between traffic analysis zones.

The ODME process iteratively updates an input O-D trip table of truck travel flows (also referred to as the “seed trip table”) using truck traffic counts as control totals. The truck model is considered validated when the assigned truck volumes from the model match well with the corresponding observed truck counts.

Model Validation: Another application that can be supported by a broad set of truck traffic counts is model validation although it cannot be conducted simultaneously with the data used in model calibration using ODME. Validation data should be independent of the calibration process. One practical approach to accomplish this objective is to use half of the truck counts for the ODME calibration and the other half of the truck counts for validation. However, in practice there may not be enough traffic counts to support both applications, there are geographic gaps in the count coverage, and counts are not contemporaneous requiring adjustment to the same base year.

Time-of-Day Analyses: Another important application of vehicle classification counts are time-of-day analyses of truck traffic volumes. Hourly counts collected over a 24-hour period can be used to develop time-of-day distributions of truck traffic volumes to analyze peak periods for truck traffic. Classification counts also allow for the comparisons of time-of-day distributions between automobile and truck traffic to understand peak-period interactions between passenger and freight traffic and to plan for the efficient movement of traffic during the peak period. Agencies can use classification counts to analyze time-of-day truck traffic characteristics by truck class and by highway facility type distinguishing between freight access routes and major freight corridors.

Trip Generation: Vehicle classification counts can also help agencies develop specialized truck trip generation models in which the highway facility generates the trips directly. This approach is different than the typical trip generation model and is intended for use only around major freight facilities such as airport cargo facilities, ports, intermodal rail yards, or major distribution centers.

Florida Department of Transportation used emerging technologies for automated vehicle recognition and classification counts. Fuel tankers were distinguished from other freight to gain a better understanding of goods movements. These data were collected for specific commodities in Ports in South Florida. By using GPS to track the operations of trucks traveling to and from those port facilities that can be identified as serving petroleum, information can be collected concerning the temporal distribution and trading partners of the truck movements serving these facilities.

In such specialized cases, counts by truck class on access routes to major freight facilities provide inputs for developing regression models for truck trip generation rates that are specific to each truck class.

Truck counts can provide the basis to develop truck trip generation rates for freight facilities as a function of economic variables to justify traffic impact fees.

Directional counts on access routes around freight facilities can be used to develop separate trip generation rates for production and attraction trips. However, the application of counts for trip generation analysis requires the availability of economic or land use data for a freight facility.

Identification of Major Freight Corridors and Access Routes: A vehicle classification count program that provides a balanced and comprehensive geographic coverage of sites on the highway network can be used to identify major freight corridors and freight access routes in the region. The analysis of locations with high truck traffic volumes serves as an essential input for defining the regional highway freight system of a region, such as the designation of critical urban and rural freight corridors and other uses for highway freight planning.

Implementation Issues

Site Selection: The success of a vehicle classification count program in terms of its applicability for regional freight planning is determined by the selection of sites for collecting counts. The best approach to site selection is an initial assessment of the truck count data needs in the region and selection of sites based on a prioritization of needs. This approach ensures that the most critical data needs in the region are satisfied by the count program and that the resources available for conducting the count program are optimized. Some examples of critical freight planning data needs that feed into the site selection process include:

- Truck volumes on truck designated screen line locations.
- Truck volumes on major freight corridors.
- Truck volumes on major freight access routes.
- Truck volumes serving major freight generators (e.g., ports, truck distribution centers).
- Truck volumes to meet specific jurisdiction truck traffic data needs.

An important consideration in the site selection process is the geographic coverage of the region, particularly if a primary application of the count data is an ODME calibration to provide input to a truck trip table.

Data Variability Issues: Finally, data variability is another important concern that should be addressed by a vehicle classification count program. In addition to time-of-day variations, truck volumes can have significant day-of-week and seasonal variations, which have not been well established compared to time-of-day truck traffic distributions. For example, seasonal changes in industrial shipment characteristics translate into seasonal variations in truck traffic volumes on the highway network. Therefore, truck counts that are typically collected on a specific day of the year cannot be representative of average annual truck traffic volumes at the location and need to be adjusted to account for seasonal variations. Additionally, longer term economic trends may impact counts, for example, the recession years 2008-2010 demonstrated lower traffic volumes than the preceding years in many metro areas.

Seasonal factors are typically derived from permanent traffic recorders that collect continuous counts. However, these locations are not typically distributed across the region with sufficient coverage of all relevant areas often providing little coverage on arterials and no coverage on collectors and local streets. Thus, vehicle classification count programs designed to capture seasonal variations on a range of road types can significantly increase the understanding of temporal variability in the region.

Finally, table 17 outlines the advantages and limitations of different vehicle classification count methods including manual observation, automated or electronic data collection, and video surveillance.

Table 17. Advantages and limitations of vehicle classification count methods.

Method	Advantages	Limitations
Manual Observation	There is no disruption of traffic during data collection.	There is a high personnel requirement for conducting manual counts and staff training.
	There is minimum risk to individual observers collecting vehicle classification counts, as they do not have to interact with the traffic flows.	Manual vehicle classification counts have the potential for human error, especially under heavy traffic conditions.
	This method may be more accurate than automatic vehicle classification counting methods. It can record both axle group and number of units, enabling vehicle classification by the FHWA 13-group classification system.	Manual counts are not a good approach for counting vehicles during the nighttime period, as visibility can cause a problem in effective counting of vehicles by class.
Automated or Electronic Data Collection	There is no disruption of traffic during data collection after automatic vehicle recording equipment are placed on the pavement.	There is a potential for equipment failure, which will impact the accuracy of the collected counts.
	This method is most efficient when classification counts are needed at many sites. Higher efficiency in data collection is achieved with minimum labor requirement.	This method counts vehicles only based on a classification system (e.g., number of axles). There is a potential for error when converting counts from one classification system to the other.
Video Data Collection	There is no disruption of traffic during data collection.	This method has high equipment costs, especially for larger geographic coverage areas.
	This method offers the ability to stop the video and conduct quality checking of data.	Weather can have a serious impact on video count programs, due to the potential for equipment failure or reduced visibility.
	Method can provide better information on type of truck (and type of commodity hauled) compared to automated counting methods.	

NEW SURVEY METHODS

Freight data are collected as part of many truck operations such as fleet management, automatic vehicle location, and GPS tracking. These sources provide information on truck locations and travel times both when trucks are moving and when they are stopped. To preserve the confidentiality of private truck operations, the identifying information of the device providing this information is typically replaced by an anonymous ID before it is made available.

While these data have the potential to replace or supplement trip dairies, the truck stops that are reported in trip diaries must first be inferred from all position- and time-stamped truck data. To make use of confidential information, these inferences are often made by third parties that acquire this information. Typical vendors include the ATRI, StreetLight Data, INRIX, and AirSage.

The inference of time and location of truck stops does not provide access to other useful information, such as truck size, body type, and ownerships or its contents (type of freight, other goods, service tools and supplies, or empty). While these data sources have the potential to provide massive amounts of data, they provide limited information about the characteristics of those operations. Many other data sources also provide information about location based services (LBS); however, information from devices such as smartphones will also be anonymized and it is often not possible to determine if the LBS information is derived from a truck driver or some other traveler.

The collection of local data has been the topic of considerable research. A useful guidebook on this topic is NCFRP Report 37: Using Commodity Flow Survey Microdata and Other Establishment Data to Estimate the Generation of Freight, Freight Trips, and Service Trips, which is available at https://www.nap.edu/download/24602.

Data Sharing Between Public and Private Sector

The availability of massive amounts of data from new sources is a major change in data usage. Data on normal business operations, particularly trucking operations, are being recorded and transmitted electronically. This has the potential to provide substantially more data than was available previously, but may not provide the detail and precision that can typically be collected with direct surveys and interviews of establishments and truck drivers.

Public transportation agencies can consider arrangements with private data firms to obtain data for freight planning and modeling. These arrangements can provide agencies with access to data with large samples and new attributes. There are challenges concerning data privacy since the trucking industry manages data that are often considered sensitive and proprietary. Governments have legitimate needs to obtain industry data, but State and Federal laws make it challenging for government agencies to enter into legal arrangements to protect proprietary data. Data privacy agreements can be developed that include restrictions on use, sharing, and collection of the data. Another option is to obtain data through a “trusted third party,” who can act as stewards for proprietary industry data and related data-sharing partnerships.

A major source of difficulty is attributing movements to freight and truck operations. To protect the confidentiality, the data must be anonymized and identifying information must be suppressed before a dataset is made available to freight practitioners. Location data collected from travelers' cell phone devices can be translated to travel patterns, but it is critical to identify individuals operating a vehicle carrying freight (e.g., a truck driver) instead of the public. It may be possible to determine the location and time associated with travel, but unless the traveler can clearly be identified as operating a vehicle that carries freight, LBS data may not provide useful information for freight trucks.

Integration of Different Approaches to Freight Data

The Freight Demand Modeling and Data Improvement program (SHRP2 C20) funded many innovative data collection projects, some of which are included as examples in earlier sections. These projects listed below are examples of innovative data collection:

- Mid-America Regional Council combined existing data with new sources of commercial freight waybill data on shipment origin, destination and cost. This was used to calculate performance measures on the cost of congestion for moving goods through urban areas. Techniques were developed to identify data that can highlight the difference between short term and long-term trends. The information was extracted from analysis of freight waybill data and can be used to analyze trips and costs of freight movements in the region.

- Capital District Transportation Committee coded freight data to zip code and/or traffic analysis zones (TAZs) to more accurately characterize freight movements in the region for use in regional freight planning and decision making. The process expanded the "Capital District's Dynamic Freight Database" to combine new data on freight with information from in-depth interviews with stakeholders.

- Delaware Valley Regional Planning Commission supplemented its ongoing freight data collection program to tabulate and visualize various types of nationally available data. The PhillyFreightFinder data repository has served the data needs of the public and private sector in the Philadelphia metropolitan area. Supplemental data sources were identified for the ongoing PhillyFreightFinder data collection effort and an increased amount of data was presented on the clearinghouse. Plans were developed to share and maintain the data and tool through open source products and to enhance the data clearinghouse's replicability for use by agencies nationwide.

- South Dakota Department of Transportation (SDDOT) concentrated its activities on commodities in the agriculture industry and related transportation system demands. Historical trend data were supplemented with new nontraditional data sources including waybills, privately held data, and remotely sensed data. The interaction with railroads, shippers, agricultural industry experts, and local producer groups enhanced the data collection and understanding of agricultural shipment data.

- Washington State DOT also focused on specific commodities including the food distribution supply chains in central Puget Sound and the cross-State wheat supply chains. The data were collected from truck count data at food distribution facilities with a variety of other land uses. This information was supplemented by interviews and questionnaires concerning the characteristics of businesses. Shipment data were collected from freight originators, receivers, and transportation providers, to shed light on how decisions are made for movements across supply chains.

These projects demonstrated that it was possible to focus on commodities that are important to a region by linking data collection efforts to facilities that serve those commodities. Effective engagement with the private sector helped to ensure that data collection activities would support transportation planning decisions and help strengthen the involvement of private sector stakeholders.

PART C. METHODS

Transportation demand is often expressed in a table or matrix that sums flow attributes (vehicles, commodity tonnage) for every Origin-Destination (O-D) pair in a State, region, or subareas. Demand on specific links in transportation networks is determined based on the assignment of O-D demand as reflected in tables. Practitioners then evaluate the volumes on the network links to the attributes of their links to determine transportation performance.

Figure 9 shows a simple but useful equation to formulate the volumes on a network:

$$V_l = \sum_{ij} t_{ij} * p_{ijl}$$

Figure 9. Equation. Link volume formulation.

Where:

V_l = The volume on network link *l*.

t_{ij} = The O-D table of demand between zone *i* and zone *j*.

p_{ijl} = The portion of demand, between zones *i* and *j* that are assigned to link *l*.

While there are three variables in this equation, only the link volumes and the O-D table of demand can be considered in forecasts. The routing table assignment deals with how the demand in the O-D table uses network links that serve demand.

Part C presents the analysis methods in increasing order of complexity. All methods share a common framework; each requires a trip table of geographic freight demand and uses a process to assign that demand to the modal networks that serve that geographic demand.

- Chapter 6 describes the simplest method, using forecasts that are prepared by others.
- Chapter 7 discusses how to use existing forecasts to produce new forecasts of demand by factoring the existing forecasts.
- Chapter 8 outlines how to acquire and process a geographic table of freight demand and use that to develop network flows.
- Chapter 9 details how to use acquired estimation data to develop trip based models that forecast tables of targeted geographic demand and volumes on network links.
- Chapter 10 explores how to use acquired estimation data to develop supply chain tour models, which can be unlinked into tables of geographic demand and assigned to develop forecasts of volumes on networks.
- Chapter 11 describes a framework that considers non-freight trucks along with freight by all modes.

Table 18 illustrates the freight and non-freight forecasting elements for the methods presented in chapters 6 through 10.

Table 18. Forecasting elements by method.

Type	Elements	Chapter 6	Chapter 7	Chapter 8	Chapter 9	Chapter 10
Freight (All Modes)	Trip Table	Existing	Factored	Existing	Forecast	Forecast
	Volumes	Existing	Factored	Forecast	Forecast	Forecast
	Performance	Existing	Forecasts	Forecast	Forecast	Forecast
Non-Freight Trucks	Trip Table	N/A	N/A	N/A	Forecast	Forecast
	Volumes	N/A	N/A	N/A	Forecast	Forecast
	Performance	N/A	N/A	N/A	Forecast	Forecast

CHAPTER 6. EXISTING FORECASTS

Developing freight demand forecasts requires extensive data and considerable resources. Forecasts that support transportation analysis and investments undergo considerable scrutiny, so it is important that they accurately reflect current base-year conditions and achieve consensus among experts. To minimize the resources required to create high-quality forecasts, transportation agencies may choose to use existing forecasts developed and vetted by other agencies. This chapter describes methods for reformatting and utilizing existing forecasts.

The existing forecast method, uses trip tables and/or network assignments and performance measures. Agencies using the existing forecast method prepare freight plans/analysis based on usage and performance forecasts prepared by others. In the case of freight/truck planning, practitioners should recognize that existing forecasts have a different understanding of the transportation system that may not be compatible with their current analysis. Transportation issues identified in existing forecasts may not include or consider aspects that are of interest to the agency adapting these forecasts.

Table 19 summarizes the pros and cons of relying on existing forecast under different scenarios.

Table 19. Strengths and weaknesses of using existing forecasts for freight analysis.

	Element	Remark
Pros	Data readily available to start analysis.	To use National Highway Freight Program funding, States are required to have a State freight plans. These are typically developed with MPO involvement. MPOs are strongly encouraged integrate freight into their planning process, and to develop metropolitan freight plans.
	Broadly used data and reports prepared by others.	Reports of usage and performance, especially if they are used to justify expenditures, may be more credible if the reports of forecast usage and performance are prepared by someone other than the project sponsor.
	Requires fewer specialized resources.	By not having to prepare forecasts of usage and performance, and relying on those prepared by other, fewer specialized resources are required.
Cons	Indirect impacts on usage and performance not considered.	Emerging issues may not have been factored in to existing forecasts. Changes in usage and performance as a result of different scenarios for infrastructure improvements or policy changes cannot be modeled.
	Forecasts may not be consistent with local plans or forecasting assumptions.	Transportation usage and performance prepared by others, and thus may not be consistent with an agency's own forecasts of the economy and those transportation forecasts cannot be easily changed.
	Reports of demand and performance may not differentiate by type of demand (e.g., by commodity or by truck size).	By using the reports of existing and/or forecasts of usage and performance, it is limited to only the usage and performance that is reported. For example, the reported FAF highway network assignment does not differentiate truck volumes by type of commodity or by truck size.

FREIGHT DEMAND

Freight forecasts can be obtained from a variety of sources, including economic development agencies, chambers of commerce, and facility operators. These agencies and groups have prepared forecasts for their own purposes and the freight forecasts may only be a subset of other socioeconomic forecasts.

As noted in chapter 4, the most common commodity flow databases, the Freight Analysis Framework (FAF) and TRANSEARCH, include a base year and one or more forecast years. A transportation agency may reformat and report these forecasts instead of developing new forecasts. While this approach requires fewer resources, the basis for the forecasts may not be disclosed and cannot be changed; analysts may need to format the forecast to fit the geography, commodities, and modes of interest to the transportation agency. When reformatting, analysts can aggregate the forecasts to a less detailed geography or disaggregate an existing aggregate forecast to a more detailed geography. Chapter 4 further discusses the geographic disaggregation process.

FAF provides an online tool for obtaining existing FAF forecasts specific to:

- Type of flow (Total, domestic, import, or export).
- Origin (State, FAF zone, or metropolitan area).
- Destination (State, FAF zone, or metropolitan area).
- Distance band (<100 miles, 100-249, 250-499, 500-749, 750-999, 1,000-1,499, 1,500-2000, and >2,000 miles).
- Commodity (SCTG codes).
- Mode (Truck, rail, water, air, or multiple).
- Measure (Tons, ton-mile, or values).

Table 20 shows an example of reformatting and aggregating the FAF flows for a single State, created from the FAF tool available at: https://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

Table 20. 2015 Alabama aggregated freight analysis framework flows (FAF version 4).

Trade Type	Domestic Mode	Within the Given State		Outbound from the Given State		Inbound to the Given State	
		(O1 to O)		(O to all other States)		(all other States to O)	
		Constant $ (Within)	Percentage (Within)	Constant $ (Outbound)	Percentage (Outbound)	Constant $ (Inbound)	Percentage (Inbound)
Total	Total	117,188	100.0%	162,824	100.0%	183,971	100.0%
Domestic Only	Sub Total	104,673	89.3%	138,761	85.2%	160,991	87.5%
	Truck	97,217	83.0%	92,661	56.9%	108,369	58.9%
	Rail	1,023	0.9%	7,688	4.7%	7,655	4.2%
	Water	4	0.0%	711	0.4%	3,804	2.1%
	Air (include truck-air)	7	0.0%	356	0.2%	1,652	0.9%
	Multiple modes and mail	4,206	3.6%	20,617	12.7%	18,902	10.3%
	Pipeline	2,216	1.9%	16,728	10.3%	20,609	11.2%
	Other and unknown	0	0.0%	0	0.0%	0	0.0%
Export	Sub Total	4,485	3.8%	17,265	10.6%	5,965	3.2%
	Truck	3,490	3.0%	10,757	6.6%	852	0.5%
	Rail	767	0.7%	2,719	1.7%	465	0.3%
	Water	35	0.0%	59	0.0%	358	0.2%
	Air (include truck-air)	3	0.0%	1,857	1.1%	4,059	2.2%
	Multiple modes and mail	158	0.1%	1,869	1.1%	231	0.1%
	Pipeline	32	0.0%	0	0.0%	0	0.0%
	Other and unknown	0	0.0%	5	0.0%	0	0.0%
Import	Sub Total	8,031	6.9%	6,798	4.2%	17,015	9.2%
	Truck	4,372	3.7%	3,614	2.2%	6,703	3.6%
	Rail	2,903	2.5%	621	0.4%	3,986	2.2%
	Water	229	0.2%	663	0.4%	377	0.2%
	Air (include truck-air)	247	0.2%	1,056	0.6%	1,401	0.8%
	Multiple modes and mail	219	0.2%	835	0.5%	4,515	2.5%
	Pipeline	57	0.0%	0	0.0%	0	0.0%
	Other and unknown	4	0.0%	9	0.0%	33	0.0%
	No domestic mode	0	0.0%	0	0.0%	0	0.0%

[1] "O" refers to the origin State, which in this case is Alabama.

(Source: FAF.)

Commodity Flow Table

Transportation agencies may express a trip table of freight demand in terms of the geographies, purposes/commodities, modes, and time periods. While these are all useful to transportation agencies, it is more likely that an agency will need to reformat those forecasts from their original presentation to fit their own needs. In addition to reformatting, agencies may need to extract only those portions of the trip table that are of interest. For example, agencies will not need the reporting of FAF flows between California and Oregon when preparing freight forecasts specific to Virginia. Once the trip table is in a format that is useful to the agency, it may be aggregated to identify:

- Freight flows that have origins or destinations outside of the U.S., (i.e., imports and exports).
- Major freight flows by the domestic origins and destinations (i.e., top trading partners).
- Major freight flows by the modes used (i.e., top modes).
- Major freight flows by the commodities carried (i.e., top commodities).

Practitioners may reformat, but not modify, existing forecasts of freight trip tables, especially without some understanding of the underlying assumptions about the relationship between the commodities and the economy used to make the existing forecasts. If an existing forecast is modified, practitioners need to explicitly identify the basis and the assumptions involved in the modification process. In these cases, practitioners cannot present the resulting data as the source material; they should present these data as a new forecast using the new assumptions underlying the process.

Assignment

The forecast of trip tables by mode allows analysts to assign these trip tables to their respective modal network. TRANSEARCH provides routing tables that analysts can use to prepare network flows for truck/highways and rail, while the FAF provides weekday highway network truck flows. TRANSEARCH flow units for trucks include annual tons and the corresponding value of goods transported. Regardless of the flow units used from TRANSEARCH, the assignment principle is the same.

The FAF highway assignment considers routing restrictions, converts annual tons to daily trucks, and disaggregates the larger FAF regions to smaller regions (freight activity zones) prior to assignment. The complete FAF highway assignment is a complex procedure and has not been publicly disclosed. Both base year and future year freight truck flow estimates are available for analysis.

In addition to modal networks, freight flows begin or end at terminals included in this network. The location of major terminals is publicly available and discussed in chapter 4. The precise usage of these terminals is indiscernible from the FAF network, and any data on them can be obtained from local data collection or existing local forecasts.

Performance

Existing travel forecasts may also include a network performance forecast. Using factors such as volume to capacity ratio, the analyst can identify the locations where congestion is likely, delays are probable, and/or reliability may be poor. These types of freight bottlenecks provide insight into delays to freight movement. If an analyst compiled performance from stakeholder assessments, the analysis will reflect existing bottlenecks and may not include locations where increased demand on the system will create new bottlenecks.

NON-FREIGHT TRUCKS

Since non-freight trucks are often moving on the same system as freight trucks, forecasted traffic conditions may affect non-freight trucks differently based upon differing travel characteristics. The demand or performance forecasts for all trucks may not distinguish between freight and non-freight trucks, an important distinction to consider when using these forecasts.

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CHAPTER 7. GROWTH FACTOR METHODS

When a formal forecast of freight flows is not available, transportation agencies may use the growth factor method to adjust up or down trip tables and/or assignments that have been prepared by others. The growth factor method assumes that the basic patterns in transportation forecasts, including economic assumptions and the usage of the transportation network, do not change.

This chapter discusses three broad methods of growth factoring that include forecasting future activity based on historical traffic trends; forecasts of the underlying economic activity; or forecasts of freight commodity flows. Analysts may use factoring to account for new activity related to a specific project. The pros and cons of this method are outlined in table 21.

Table 21. Strengths and weaknesses of the growth factor methods.

Elements		Remarks
Pros	It can focus its efforts on forecasts for specific facilities.	The new forecasts can be focused on the incremental impact of new facilities, and do not need to produce forecasts for unrelated facilities.
	Resources requirements are lessened.	Factoring typically requires a minimal effort, is easy to understand, and does not require specialized staff and/or skills.
	It relies on easily obtained information.	The information used in factoring is typically readily available and has been reviewed by others. Only the growth rates implied by this information need to be used in this effort.
Cons	Factoring cannot change the usage and the performance of background flows.	The factored flows are typically only added to an existing forecast of usage and performance, e.g., freight flows to or from a new facility. This method will not change the background data of the existing forecast. While changes to new flows can be added to this background, factoring assumes that existing usage and performance will not change due to these new facilities.
	The usage and performance of these new facilities may not have been considered when the background forecasts were prepared.	This method can only change the usage and performance from new facilities. Those new facilities could obviously not have been included in those background forecasts. If the new factored growth is expected to change those background forecasts, for example a new road that is expected to change the background traffic pattern, then this method may not be appropriate.

Factoring existing freight demand is a simple and direct method to forecast future freight demand. Analysts can develop and apply the factors to adjust network volumes, trip tables, trip ends, and/or specific trip movements. When applied to trip tables or flows within trip tables, the resulting forecast may be summarized and reported or assigned to a network.

The development of growth factors needs to be consistent and the unit of measurement must be the same across all observations/forecasts. For example, analysts can develop factors from historical truck counts, since all observations refer to truck traffic. The growth factors themselves are unitless and represent a rate that can be applied to the existing forecast. When applying growth factors, practitioners assume that the movement of freight correlates to the source of the growth factors. For example, applying growth factors developed from forecasted employment growth assumes a direct correlation between changes in employment and freight movements.

Figure 10 shows the freight demand factoring method for adjusting and assigning trip tables.

This chapter provides simple methods that practitioners can use to forecast the changes in freight usage and performance due to changes in the level of economic activity or other related factors.

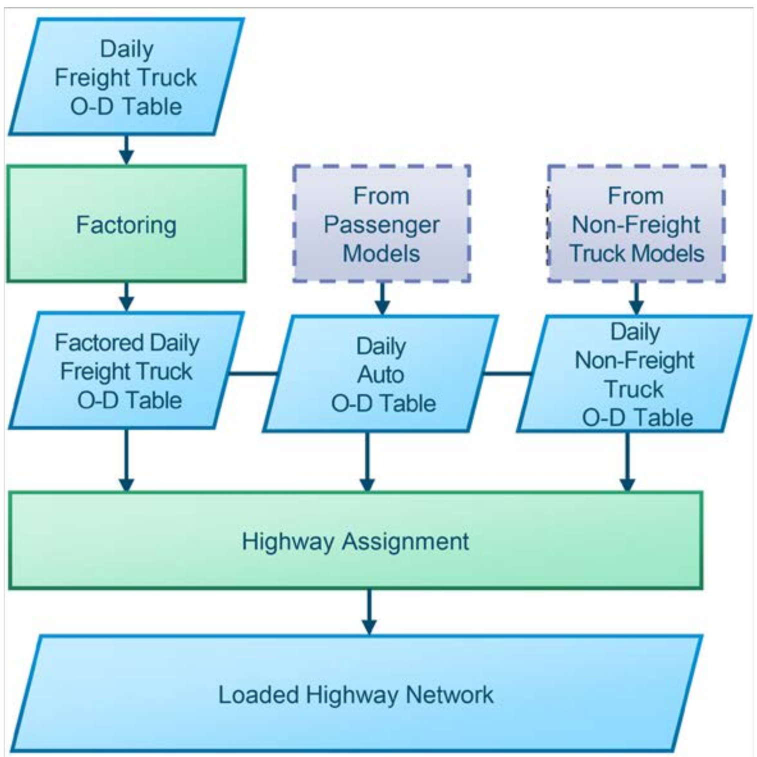

Figure 10. Flowchart. Growth factor method example.
(Source: Federal Highway Administration.)

Table 22 shows the growth factor approach applied to the trip tables and/or assigned network volumes can be classified into three types.

Table 22. Approaches to estimating growth factors.

Approach	Process
Forecasting future activity based on *historical traffic trends.*	Involves the direct application of a growth factor, calculated based on historical traffic information, to the baseline traffic data.
Forecasting future activity *based on forecasts of economic activity.*	Recognizes that demand for freight transportation is derived from underlying economic activities (e.g., employment, population, and income). Forecasts of changes in economic variables are used to estimate the corresponding changes in freight traffic.
Forecasting future activity based on *freight commodity flow forecasts.*	Relies on forecasts of freight commodity flows that have been prepared by others at a larger geographic scale, which are then used to factor growth at a local level.

The use of growth factors is a simple, inexpensive way to forecast freight based on historical trends, historical relationships to economic data, or commodity forecasts prepared by others. However, this method assumes that the relationships that underlie the history or forecasts will continue during the forecast period. This approach is not well suited for situations that involve dramatic new changes in activity, such as the development of a new industry or a major freight facility. The growth factor method is best suited for analyzing incremental changes in freight activity.

GROWTH FACTORS BASED ON HISTORICAL FREIGHT TRENDS

Analysts can fit historical data to a curve using linear or nonlinear regression, depending on the desired curve and the shape of the underlying data patterns. This section presents simple procedures for using historical data to project future freight demand. Regression that fits the data along a line or a curve can be determined using spreadsheet functions or statistical software packages. When using historical trends for forecasting, the assumption made is that past trends will continue into the future.

Linear Growth

Assuming that freight flow grows in a linear fashion, sometimes called simple growth, the annual growth factor (AGF) rate is the difference between the flow in the first observation and the flow in the second observation divided by the time increment, typically measured in years, between those observations, shown in figure 11.

$$AGF = (F_2-F_1)/(Y_2-Y_1)$$

Figure 11. Equation. Annual growth factor definition.

Where F_1 is freight flow in year Y_1 and F_2 is freight demand in year Y_2.

The linear AGF can then be applied to predict future demand (F_3) for a future year (Y_3) as shown in figure 12.

$$F_3 = F_2 + AGF*(Y_3 - Y_2)$$

Figure 12. Equation. Calculation of future freight demand based on average annual growth factor.

For example, the number of truck trips at a given location on an average weekday is 8,000 in 2010 and 10,000 in 2015 (figure 13). Using this linear growth procedure, the forecasted number of truck trips for the year 2020 is 12,000 (figure 14).

$$AGF = (10{,}000-8{,}000)/(2015-2010) = \mathbf{400}\text{/per year})$$

Figure 13. Equation. Example of an annual growth factor calculation.

$$12{,}000 = (10{,}000)+(\mathbf{400})*(2020-2015, 5\text{ years})$$

Figure 14. Equation. 2020 truck trips forecast based on 2015 traffic and the annual growth factor.

When analysts have more than two years of historical data available for the forecasted variable, they can use these data to solve a linear regression according to the formula in figure 15.

$$F(n) = \text{Constant} + AGF*(n)$$

Figure 15. Equation. Regression equation forecasting freight demand using the annual growth factor.

Where n is the number of years from the first observation and Constant and AGF are found from the linear regression.

Table 23 shows an example using a spreadsheet regression package. In this application, the linear regression solution yields both the intercept and the x-variable coefficients, which are the Constant and the AGF, respectively.

In this case, the linear regression model has a good overall fit with an R-Square value of 0.812, and the forecasting formula for freight tons is expressed in figure 16.[9]

$$F(n) = 104{,}739+1{,}357*(n)$$

Figure 16. Equation. Example of a linear regression equation forecasting freight tons.

The underlying data and the forecasts of freight tons in the future results are shown in table 23; the forecasts of the regression model for current and future years are shown the last column.

[9] R-Square is the proportion of the variance in the dependent variable that can be explained by the independent variable(s); it is used to represent the goodness of fit of a model.

Table 23. Linear growth regression model for forecasting freight tonnage.

Year	Tons	Years from 2003	Linear Regression
2003	104,432	0	104,739
2004	111,955	1	106,096
2005	101,807	2	107,453
2007	109,659	4	110,168
2013	117,896	10	118,311
2014	120,266	11	119,668
2015	121,445	12	121,025
2020	–	17	127,811
2025	–	22	134,597
2030	–	27	141,382

Compound Growth

Compound freight flow growth is similar to compound financial growth; the AGF is the ratio of the flow in the second and first observations raised to a power that is the inverse of the difference of years between the first and second observations, shown in figure 17.

$$AGF = (F_2/F_1)^{(1/(Y_2-Y_1))}$$

Figure 17. Equation. Compound annual freight growth definition.

Where F_1 is freight flow in year Y_1 and F_2 is freight demand in year Y_2. This also can be expressed as a compound annual growth rate by subtracting 100 percent from the AGF.

The compound growth factor can then be applied to predict future demand (F_3) for a future year (Y_3), as shown in figure 18.

$$F_3 = F_2 * AGF^{(Y_3-Y_2)}$$

Figure 18. Equation. Future freight demand formula using compound average growth.

For example, the number of truck trips at a given location on an average weekday is 8,000 in 2010 and 10,000 in 2015 (figure 19). Using this compound growth procedure, the forecast number of truck trips for the year 2025 is 15,625 (figure 20).

$$AGF = (10{,}000/8{,}000)^{1/5} = \mathbf{1.04564}$$

Figure 19. Equation. Example of calculating compound annual growth.

$$15{,}625 = (10{,}000)\ (\mathbf{1.04564})^{10}$$

Figure 20. Equation. 2025 truck trips forecast based on historical traffic and compound growth.

The compound annual growth rate can be calculated as 4.6 percent (104.564 percent minus 100 percent).

When analysts have more than two years of historical data available for forecasting freight traffic, they can use these data to solve a power regression according to the formula in figure 21.

$$F(n) = Constant*AGF^{(n)}$$

Figure 21. Equation. Power regression definition.

Where n is the number of years from the first observation and the variables Constant and AGF are estimated from the linear regression application.

Table 24 shows an example using a spreadsheet regression package. The data are organized in columns where the x-variable (independent variable) is Years and the y-variable (dependent variable) is the Tons expressed as a natural logarithm, Ln (tons).

In this application, the linear regression solution provides estimates of both the intercept and the x-variable coefficients. Analysts need to convert these estimates from natural logs to whole numbers by taking the exponential of those terms with Constant = Exp (intercept) and AGF = EXP (x-variable coefficient).

In this case, the regression model has a good overall fit with an R-Square value of 0.798 and figure 22.

$$F(n) = 104{,}794*(1.012)^{(n)}$$

Figure 22. Equation. Power regression equation for forecasting freight tons.

The results are shown in the last column of table 24. This regression can translate to a compound growth rate of 1.2 percent (101.2 percent minus 100 percent) per year.

Table 24. Compound growth regression.

Year	Tons	Ln (Tons)	Years from 2003	Compound Regression
2003	104,432	11.556	0	104,794
2004	111,955	11.626	1	106,064
2005	101,807	11.531	2	107,350
2007	109,659	11.605	4	109,970
2013	117,896	11.678	10	118,217
2014	120,266	11.697	11	119,650
2015	121,445	11.707	12	121,101
2020	–	–	17	128,623
2025	–	–	22	136,613
2030	–	–	27	145,099

Forecasters can create regression equations using historical data of freight traffic or freight tons using either a linear growth approach or a nonlinear regression technique. The compound growth regression is one of many nonlinear regressions using any number of curve fitting techniques.

Linear growth will always be less than the compound growth, as shown in figure 23, using the values shown in table 23 and table 24. The choice of a growth factor method should be consistent with the pattern of the observed data and with the intended purpose of the forecast. Analysts using growth factor methods should also recognize the uncertainly of the forecast and the risk of being either too low or too high for the intended use.

For example, an analyst may use a conservative approach in cases of forecasting truck volumes to support pavement designs. In this case, the analyst may prefer to be on the high side, which would lead to the use of a compound growth approach. Conversely, freight forecasts that are input to financial analysis such as tolling should be on the low side, so analysts may select a linear regression.

Regressions can be successfully calculated even if observations are not available for all years, and they should only be used for a time period that is consistent with the period of observations. Using historical growth factoring techniques to forecast growth for a period much longer than the timeframe of the observed freight data assumes that the underlying patterns will not change during the forecasting period. Such an assumption may not be appropriate, especially in cases where practitioners expect growth patterns to change in response to major investments of newly planned infrastructure. In table 23 and table 24 the forecast for 2025 is consistent with the period of observation, but the forecast for 2030 is further away from the observation period and should be used with greater caution.

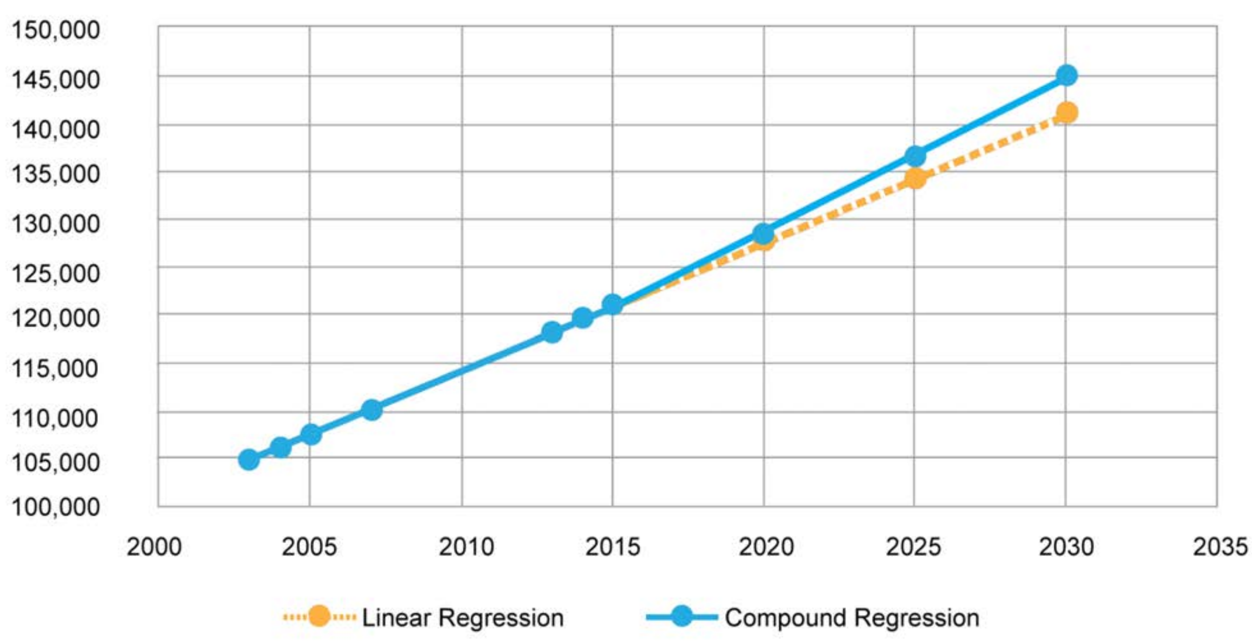

Figure 23. Graph. Comparison of linear and compound growth results example.
(Source: Federal Highway Administration.)

GROWTH FACTORS BASED ON DIRECT ECONOMIC PROJECTIONS

This section presents a simple procedure for forecasting freight using projections of future demand or output for the transported goods. The sections describe various sources of economic forecasts that analysts can use to apply these procedures and methods to improve the accuracy of their forecasts, and it also covers sensitivity analysis and alternative futures as part of using growth factors based on economic projections.

The approach for deriving forecasts of future freight traffic from economic forecasts assumes that the demand for transporting a specific category of freight is directly proportional to an economic indicator variable that measures output or demand for that category. With this assumption, analysts can use growth factors for economic indicator variables as growth factors for freight traffic.

Using Economic Output

This procedure requires freight traffic data or estimates by category/commodity type for a "normal" base year and the base and forecast year values for the corresponding economic indicator variables. The basic steps involved in the process are as follows:

1. Select the commodity or industry groups to be used in the analysis. This choice is usually dictated by the availability of forecasts of economic indicator variables. These forecasts may reflect economic activity, for example Gross State Product (GSP), or employment in the industry groups associated with each category/commodity.

2. Obtain or estimate the distribution of base year freight traffic by category/commodity and its associated industry group. Analysts may receive these data from an intercept survey of vehicles traveling around the facility for which they are preparing forecasts. If such observed data are unavailable, State or national sources may be used to estimate this distribution. The AGF for each economic sector or industry group can then be determined by the equation in figure 24.

$$AGF = (I_2/I_1)^{1/(Y_2-Y_1)}$$

Figure 24. Equation. Average growth factor as a function of an economic indicator.

Where I_1 is the value of the economic indicator in year Y_1 and I_2 is the value of the economic indicator in year Y_2.

3. Use the AGF and base year traffic to calculate forecast year traffic for each commodity or industry groups using the equation in figure 25.

$$T_f = T_b * AGF^n$$

Figure 25. Equation. Forecast of truck traffic by commodity or industry group.

Where subscript *b* indicates a base year of the traffic, subscript *f* indicates a forecast year, and the power *n* applied to the AGF is the number of years in the forecast period.

4. Aggregate the forecasts across economic sectors or industry groups to produce the forecast of total freight demand.

Using Employment

Alternatively, if the mix of traffic by economic or industrial sector is unavailable and national sources are not useful, analysts can convert employment forecasts to truck trips using available truck or vehicle trip rates for the economic indicator variable. In this case, the method is as follows:

1. Select the industry groups to be used in the analysis. This choice is usually dictated by the availability of forecasts of economic indicator variables. These forecasts may project economic activity; for example, GSP forecasts or forecasts of industry groups' employment associated with each category/commodity.

2. Calculate the base year number of freight units, such as truck trips, for each sector based on the economic indicator variable and the freight units, such as truck trip rates for that sector. Calculate the forecast year number of trucks for each sector based on the economic indicator variable and the truck trip rates for that sector.

3. Sum all of the truck trips for the base year and for the forecast year. Determine the total AGF using the equation in figure 26.

$$AGF = \left({}^{Forecast\ in\ Y1}\!/\!{}_{Forecast\ in\ Y2}\right)^{1/(Y_2 - Y_1)}$$

Figure 26. Equation. Average growth factor using data from multiple industry sectors.

Where I_1*FR is the value product of the economic indicator multiplied by and the flow rate (e.g., truck trip rate) for that economic indicator in year Y_1 and I_2*FR is the value product of the economic indicator and multiplied by the flow rate for that economic indicator in year Y_2.

4. Apply the total growth rate to the base freight flow to determine future freight demand.

The most desirable indicator variables are those that measure goods output or demand in physical units such as tons or cubic feet. However, forecasts with such variables are often unavailable. More commonly available indicator variables are constant-dollar measures of output or demand, employment, or, for certain commodity groups, population or real personal income. The following section describes the data sources for forecasts of some of these economic indicator variables.

Sources of Economic Forecasts

Economic forecasts should apply to the area being served by the freight facility. There are several sources to obtain estimates of growth in economic activity by geographic area and by industry or commodity type. However, the availability of data specific to the geographic areas and industries under consideration may be limited, forcing the analyst to make compromises. While transportation agencies have historically used forecasts of employment it should be noted that this employment is major determinant in the overall volume of freight, the forecasting of firms by size, which determines shipment size and frequency that may be desirable. While forecast of employment by industry might be available, transportation agencies may also need to develop forecasts of the number and size of firms to provide the data that will be needed to determine what modes/supply chains will be used.

Many States fund research groups that monitor the State's economy and produce forecasts of changes in the economy. For example, the Center for the Continuing Study of the California Economy develops 10-year forecasts of the *value* of California products by the NAICS code.[10] Similarly, the Texas Comptroller of Public Accounts develops 10-year forecasts of *population* for 10 sub-State regions and 10-year forecasts of *output* and *employment* for 14 industries.

At 2.5-year intervals, the Bureau of Labor Statistics (BLS) publishes 10-year forecasts of *output and employment* for 242 sectors generally corresponding to three- and four-digit NAICS industries.[11]

In addition to the State and Federal agencies, short- and long-term economic forecasts are available from several private sources. Private firms use government and industry data to develop models and analyses. Among the best known private sources are IHS Markit and Woods and Poole.

IHS Markit provides national, regional, State, metropolitan statistical area (MSA), and county-level macroeconomic forecasts on a contract or subscription basis. Forecasts of key variables include gross domestic product, employment, imports, exports, and interest rates. Their U.S. county-level forecasts cover a 30-year period and contain annual data. Forecasts are available on a semiannual basis, with more than 30 concepts forecasted, including income and wages, employment for 11 major industry categories, population by age cohorts, and households by age cohorts. The U.S. county forecasts are updated semiannually.

Woods and Poole provides more than 900 economic and demographic variables for every State, region, county, and metropolitan area in the U.S. for every year from 1970 to 2030. They update this comprehensive database annually and it includes detailed population data by age, sex, and race; employment and earnings by major industry; personal income by source of income; retail sales by type of business; and data on the number of households, their size, and their income. Woods and Poole project these variables for each year through 2030.

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[10] NAICS—The North American Industrial Classification System, a hierarchical coding system for industries.

[11] The most recent BLS forecasts are contained in U.S. Department of Labor, Bureau of Labor Statistics, Employment and Output by Industry, 2006, 2016, and projected 2026, http://www.bls.gov/emp/.

GROWTH FORECASTS USING TRANSEARCH OR THE FREIGHT ANALYSIS FRAMEWORK

This section discusses growth factoring based on economic forecasts, focusing on how analysts can use economy forecasts to develop freight growth factors. This requires developing methods that convert forecasts of the economy by sector to corresponding commodity groups.

Some commodity flows databases provide forecasts of commodity flows. Instead of trying to convert economic forecasts to commodity flow forecasts, analysts can use these forecasts to develop growth factors for freight. IHS Markit provides forecasts of freight flows in its TRANSEARCH database when licensed for this purpose. IHS Markit also provides the economic forecasts in the Federal Highway Administration's (FHWA) Freight Analysis Framework (FAF) database, which are publicly available. The FAF forecasts, available from https://faf.ornl.gov/fafweb/Data/FAF4.5.zip, are the mid-range economic forecasts for commodity flows. The high and low FAF forecasts for commodity flows are also available from https://faf.ornl.gov/fafweb/Data/FAF4.5_HiLoForecasts.zip.

The forecasts in both TRANSEARCH and FAF represent forecasts of the national economy and analysts apply them to flows between geographic regions, not to be confused with forecasts made specifically for local economies. However, the conversion of these forecasts from economic sector forecasts to commodity flow forecasts makes them easy to apply.

COMPARISON OF GROWTH FORECASTS

The growth methods discussed in this chapter so far are simple to apply and rely on applying growth factors based on trends to grow trip tables or link flows. The growth methods that use traffic trends and economic activity forecasts are perhaps more suitable for site or corridor analysis. The method that uses freight commodity flow forecasts can also be used in site or corridor analysis but is also suitable for revising existing system wide forecasts to make them compatible with the freight forecasts, or to provide more detail such as by commodity.

Rather than just one set of factors, it may be appropriate to develop and apply growth factors using each approach when possible. A comparison can be made among the forecasts using each of the three growth factors approaches. If they are similar, it may be reasonably to conclude that the resulting forecasts are more robust. It is important to understand the underlying economic assumptions when forecast comparisons are made between data derived from different sources. It is also important to determine and document cases where different growth rates were developed using the same underlying data source. For example, economic activity derived growth rates and FAF/TRANSEARCH commodity derived growth rates may use the same underlying data source that could lead to comparable growth rates.

IMPROVING THE DEMAND FORECASTS

The growth factoring methods implicitly make the assumption that, for any transportation facility, the percentage change in transport demand (i.e., freight traffic) of each commodity group will be identical to the percentage change in the corresponding indicator variable. However, the percentage changes in freight traffic are likely to differ across transportation facilities for numerous reasons, including changes over time in:

1. Real value of output per ton, adjusted for inflation.
2. Output per employee, also known as labor productivity.
3. Transportation requirements per ton which may also affect the choice of freight mode.
4. Competition from other facilities and modes.

To the extent that analysts understand the likely effects of these changes and can estimate them at a reasonable cost, the growth factoring procedure can be modified and the forecast can be increased or decreased to reflect these effects. This section does not provide specific methods on how to adjust the growth-derived forecasts under each scenario. Instead, it provides an understanding of the direction of adjustments that will need to be made by a practitioner who would make these more realistic scenario assumptions using supporting data sources and some degree of engineering judgment.

For most commodity groups, the relationship between value of output (measured in constant dollars) and volume shipped (measured in pounds, tons, cubic feet, etc.) may change over time. These changes could be caused by a shift in commodities production within a given commodity group (e.g., more aluminum and less steel) or a fluctuation in the average real value per ton of major products within the group. Commodity mix and/or commodity value changes may result in an overall change in the value per ton of the commodity group. For example, the shift from cathode ray tube televisions to flat screen televisions represented a change in product category. When analysts forecast transport demand for several commodity groups, adjusting for changes in value per ton for all commodity groups may not have a significant effect on the overall forecast of transport demand. However, when there are one or two commodity groups of interest, analysts should consider determining how the real value per ton for these groups is changing and how it is likely to change over the forecasted period.

Employment is less closely related to transport demand than real output; however, long-term forecasts of employment are more readily available than forecasts of output. For situations where output data are not available, analysts can use employment forecasts for some purposes. As a result of improvements in labor productivity, real dollar-valued output per employee increases over time and physical output (in tons or cubic feet) tends to increase as well. Forecasts of the overall increase in real dollar-valued output per employee for goods-producing industries, such as agriculture, mining, construction, and manufacturing, are available from the public and private sources listed above, but analysts should also consider the cyclical nature of commodity prices. To avoid a downward bias in transport demand forecasts, analysts can convert forecasts of the percentage change in employment to forecasts of percentage change in real dollar-valued output by multiplying by estimated growth in labor productivity over the forecast period.

Changes in production methods that result in a reduction in domestic employment, such as a shift to off-shore manufacturing, may change the origin and distribution of freight, but not the overall shipments. Whenever relevant, analysts should adjust forecasts of demand for a facility or mode to reflect expected changes in competition from other facilities or modes. These changes may result from:

- Expected changes in relative costs.
- Elimination of base year supply constraints at the facility or its competitors.
- Future supply constraints at the facility or its competitors.
- Development of new competing facilities.

Analysts can avoid the forecasting problems resulting from base year supply constraints by choosing a base year when no significant supply constraints existed. When this is not practical, analysts can use a combination of historic data and judgment to adjust the estimates of base year facility usage to eliminate the effects of the supply constraints, thus producing estimates of base year demand in the absence of supply constraints. Analysts can apply annual growth rates or growth factors to these estimates of base year demand to produce the forecast demand.

Uncertainty Analysis

The growth factor methods presented above produce a single forecast of freight demand that allows planners to make critical decisions. However, planners are cautioned that a single point forecast is unlikely to be completely accurate; some of the assumptions (e.g., those relating to economic growth) may prove inaccurate or the procedure itself has deficiencies. Effective planning requires decisions to be reasonably tolerant of inaccuracies in the forecast because no forecast will be perfectly accurate. The conventional approach to analyzing the effects of alternative futures is performing an uncertainty analysis.

The development of forecasts requires analysts to make assumptions, either explicitly or implicitly. Some common assumptions that affect forecasts of demand for a transportation facility relate to:

- Economic growth, both nationally and locally.
- Growth in economic sectors that generate significant freight volumes handled by the facility.
- Transport requirements that may be affected by imports, exports, or changes in production.
- Modal choice, which may be affected by the cost and service of competing modes.
- Facility usage that may be affected by changes in shipment size or container size.
- The availability and competitiveness of alternative facilities.
- Value per ton of output.
- Output per employee, if the forecast uses employment as an indicator variable.
- Shifts in retail to e-commerce.

Uncertainty analysis consists of varying one or more of these assumptions to produce alternative forecasts. The most common alternative assumptions that analysts should consider relate to economic growth. Economic forecasters (including the BLS) frequently provide high and low forecasts of growth in addition to a medium (or most likely) forecasts. Analysts can use the alternative forecasts of economic growth to generate alternative forecasts of transport demand; they can use additional alternative forecasts of exogenous variables (e.g., trade) to produce an even larger set of forecasts of transport demand based on low/high growth and low/high trade. However, simply varying these exogenous forecasts will not produce a set of transport-demand forecasts that represents the full range of demand that might exist in future years of interest. To produce a better understanding of the range of demand that might exist in the future, analysts should conduct a more thorough sensitivity analysis.

One approach to conducting a more robust uncertainty analysis consists of reviewing each of the assumptions that are explicit or implicit in the analysis and generating a high-low pair of alternative assumptions that are internally consistent and likely to occur. Then analysts can generate a high forecast of demand by using all the alternative assumptions that would tend to increase the forecast and a low forecast by using all the alternative assumptions that would tend to have a downward impact. These high and low forecasts should provide planners with appropriate information about the range of transport demand that could exist in the future.

A more systematic uncertainty analysis consists of making small changes in individual analysis assumptions and groups of assumptions to determine the effect of each change on forecast demand. This produces results that provide a set of sensitivity estimates of the forecast, based on each of the assumptions and combinations of assumptions. An exhaustive sensitivity analysis provides more insight into the relationships between the various assumptions and the forecasts they produced; however, this approach requires a greater expenditure of resources.

CHAPTER 8. DIRECT ACQUISITION OF COMMODITY FLOWS

The direct acquisition of commodity flows uses forecast trip tables of freight from existing sources; it accepts the forecast trip tables as valid and uses them to process and assign the trip tables to obtain usage and performance data on networks.

Network volumes and performance estimation requires a trip table and an assignment procedure. Directly-acquired freight trip table data is often derived from models developed from survey estimation data. It is possible for freight analysts to use an expanded forecast of commodity flows in place of a forecast trip table. Many Statewide freight models rely on the assumption that analysts can transform an annual commodity flow forecast of the appropriate geographic coverage into a daily truck trip table; this survey-based trip table can be used in place of a forecasted trip table. Commodity flow survey data have typically already been statistically expanded to annual flows. To assign these freight data to a transportation network, analysts only have to format and convert the table to match the desired geography and the appropriate flow units.

Figure 27 shows the forecasting method based on the direct acquisition of a commodity flow. It uses forecasts of freight commodity tables that have been prepared by others and formatted for the study area geography. Acquired forecasts include the transportation system as it was understood by those making the forecasts and may not reflect transportation issues that are of interest to the agency that will be using those forecasts.

Table 25. Strengths and weaknesses of the direct acquisition of commodity flows.

Element		Remark
Pros	Local usage and performance can be forecast.	Acquired commodity freight flows, formatted to origin-destination (O-D) trip tables can be routed to networks providing usage and performance data for the system.
	Consistency with national commodity forecasts.	The forecasts of commodity O-D tables are available from sources that typically are prepared for much larger geographies. Directly using these tables will be consistent with forecasts for larger geographies.
	Resources required to prepare these O-D tables, and network performance and usage may be modest.	The cost of purchasing a commodity flow database and reformatting it for use as a trip table, is likely to be less than the cost to otherwise forecasting this trip table.

Table 25. Strengths and weaknesses of the direct acquisition of commodity flows (continuation).

Element		Remark
Cons	Indirect impacts are not considered.	For trip tables obtained from other sources, it is virtually impossible to use feedback processes that change the table. The acquired commodity table can be used to compute performance and usage, however that performance and usage may be inconsistent with the transportation usage and performance that was used in the preparation of those tables.
	Tables of O-D freight demand may be inconsistent with local forecast.	Assumptions made in preparing the tables may be inconsistent with local assumptions (e.g., assumptions of economic growth or trading partners in the forecasts may be different from assumptions that would be made locally). These differences can be highlighted, but it may not be possible to make the tables consistent with local forecast.
	Uses the trips tables, as is.	The O-D tables can be converted (e.g., from tons to trucks), aggregated (e.g., from many commodities to a few commodity groups), separated (e.g., to remove freight trucks from all trucks) and factored (e.g., apply overall truck growth to non-freight truck O-D tables), they cannot otherwise be changed.

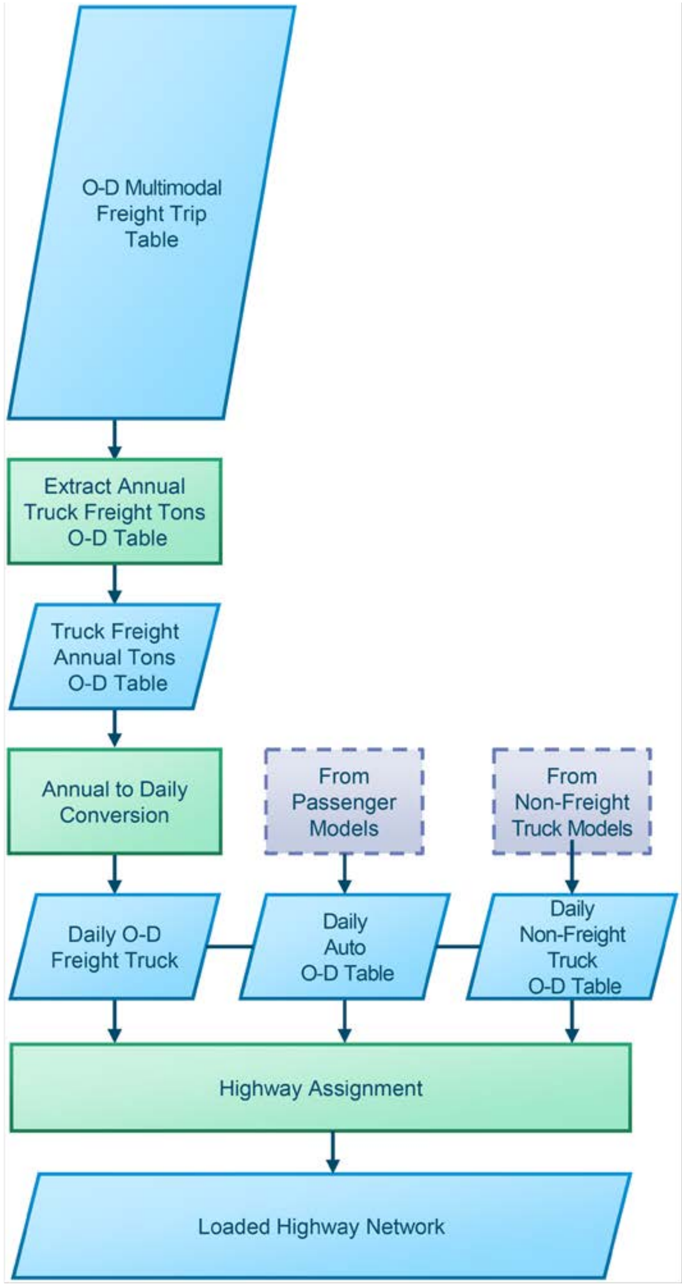

Figure 27. Flowchart. Acquired commodity flow freight forecasting method example.
(Source: Federal Highway Administration.)

Acquiring a Commodity Origin-Destination Table

There are several sources of commodity flow data, as discussed in chapter 4. A principal source is the commercially available TRANSEARCH commodity flow database, which estimates freight flows by truck, rail carload, rail-truck intermodal, water, and air at the county, business economic area, or State level. TRANSEARCH is available for base year conditions and for one or more forecast years. TRANSEARCH is not a network-assignable origin destination table, but analysts can easily transform it into such a table.

A second source of commodity flow data is the freight analysis framework (FAF), which also includes base and forecast year flows. However, the FAF is a shipper-focused database that is better suited for supply chain analysis. The FAF does not report intermediate stops, often called transport logistic nodes, which TRANSEARCH treats as origins or destinations.

In this chapter, the acquisition of a commodity O-D table focuses primarily on acquiring TRANSEARCH base year and forecast flows; it uses the TRANSEARCH definition of freight, modes supported, and commodity classification.

TRANSEARCH data purchased for a study area include detailed zones, often at the county level, and less detailed zones, such as State portions of Bureau of Economic Analysis (BEA) Economic Areas, outside of the study area. Analysts should make the commodity flow table consistent with the geographies assigned to the O-D table. For example, if the assignment network requires State level zones, analysts need to aggregate the State portions of BEAs in the acquired commodity O-D table to State level zones.

Due to the global nature of goods movements, analysts typically perform commodity flow assignments over large geographies. The assignment may be for a U.S. or North American network, with more detail within the study area and less detail outside of that study area. In cases where the network is smaller than the geography included in the commodity O-D table, analysts need to associate the flows beyond the network boundaries with external stations where freight would enter or exit the study area. In both instances, analysts should make TRANSEARCH consistent with the assignment geography.

Agencies develop commodity flow surveys from statistical samples and they expand into complete flow tables, typically for an entire year. Since these commodity flow tables are themselves a form of trip table, analysts can modify and use them as trip tables for assignment. This chapter discusses how analysts can use commodity flow surveys as trip tables in freight forecasting.

Although the organization of a commodity flow database might not look like a trip table to those who are familiar with travel demand models, practitioners can extract the necessary attribute fields from a commodity flow database and reorganize them into a trip table of freight flows. It contains attributes such as origins and destinations, commodity type (purpose), and units of flow by mode (mode share). Table 26 shows a sample frame of TRANSEARCH where the individual records contain their origin, their destination, and the commodity being transported. Analysts can transform the table into separate individual trip tables of flows (e.g., tons) between an origin and a destination for a commodity. Analysts can create multimodal tables by summing up flows over all modes and develop mode-specific tables by selecting individual freight modes.

Table 26. Indiana TRANSEARCH database sample records.

Origin Region	Origin Region Name	Destination Region	Destination Region Name	STCC4	STCC4 Name	Mode Group	Tons	Units
18107	Montgomery County, IN	134	Mississippi Portion of Memphis BEA	01 41	Livestock	Truck	0.20	0.01
18107	Montgomery County, IN	134	Mississippi Portion of Memphis BEA	20 25	Cheese or Special Dairy Products	Truck	10.54	0.46
18107	Montgomery County, IN	134	Mississippi Portion of Memphis BEA	20 85	Distilled or Blended Liquors	Truck	178.22	7.68

It is important to remember that these forecast flows are not easily modified in response to changes in employment forecasts by industry or geography, and the freight flow origins and destinations will not shift in response to changes in the transportation system that might result in new distribution patterns.

To be useful in freight forecasting, a commodity flow table must represent all flows in the geographic area, not just a sample of selected flows. In forecasting applications, analysts typically need to disaggregate these data to fit the study area, as described in chapter 5. For the commercial TRANSEARCH database, agencies can purchase information at units of geography that are smaller than the county level; however, supporting information on freight flows at smaller units is proprietary and typically unavailable to those acquiring the database.

The cost of the TRANSEARCH database is directly related to the number of records delivered. The number of records in a TRANSEARCH dataset is controlled by the level of detail requested across two dimensions: origin and destination granularity and commodity detail. Requesting greater detail in commodity data at a smaller unit of geography increases the number of records in the database.

Without assigning the database to a network, the through traffic for a particular jurisdiction is difficult to establish. For example, the analysis of the commodity flow survey (CFS) or FAF databases cannot determine what portion of the flows from California to Pennsylvania passes through Indiana. A TRANSEARCH purchase can exclude external-to-external freight flows that do not pass through a study area, although the pass through external-to-external flows are chosen by a proprietary process that windows the national TRANSEARCH to the study area using the fixed assignment process.

COMMODITY GROUPS

Analysts produce forecasts of commodity flow tables by applying economic forecasts of the industries consuming and producing freight to the related commodity flows. The direct acquisition method applies the economic forecasts directly to the observed base year freight trip table, rather than using them as an input to the trip generation and distribution methods.

Acquired commodity tables report freight flows at a very detailed level. As shown in table 26, TRANSEARCH reports commodity flows using the Standard Transportation Commodity Code at the four-digit level (STCC4). There is also a crosswalk that links the STCC4 code flows to the Standard Classification Transported Goods (SCTG2), as shown below in table 27. Both the STCC4 and SCTG2 classifications provide more information on commodities/purposes than required by freight analysts; typically, they group commodities into 10 to 20 commodity groups (CG) of similar natures important to the local economy (flows reported based on value) or infrastructure analysis (flows reported on the basis of tonnage). While analysts could acquire local commodity flow data using a simplified commodity classification system, the lack of forecasts for locally acquired commodity flow data limits their value and precludes their usage.

Table 27. Virginia Statewide Model Commodity Groups by TRANSEARCH standard classification of transported goods 2.

Virginia CG		SCTG2	
Code	**Name**	**Code**	**Description**
1	Agriculture products	01	Live Animals and Fish
		02	Cereal Grains (including seed)
		03	Other Agricultural Products, except for Animal Feed
		04	Animal Feed and Products of Animal Origin, not elsewhere classified (n.e.c.)
		05	Meat, Fish, and Seafood, and Their Preparations
2	Grains, alcohol, and tobacco products	06	Milled Grain Products and Preparations, and Bakery Products
		07	Other Prepared Foodstuffs, and Fats and Oils
		08	Alcoholic Beverages
		09	Milled Grain Products and Preparations, and Bakery Products
3	Stones, nonmetallic minerals, and metallic ores	10	Monumental or Building Stone
		13	Nonmetallic Minerals, n.e.c.
		14	Metallic Ores and Concentrates
4	Natural Sands	11	Natural Sands
5	Gravel and Crushed Stone	12	Gravel and Crushed Stone
6	Coal	15	Coal

Table 27. Virginia Statewide Model Commodity Groups by TRANSEARCH standard classification of transported goods 2 (continuation).

<table>
<tr><th colspan="2">Virginia CG</th><th colspan="2">SCTG2</th></tr>
<tr><th>Code</th><th>Name</th><th>Code</th><th>Name</th></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Fuel products</td><td>17</td><td>Gasoline and Aviation Turbine Fuel</td></tr>
<tr><td>18</td><td>Fuel Oils</td></tr>
<tr><td>8</td><td>Coal and Petroleum Products, n.e.c.</td><td>19</td><td>Coal and Petroleum Products, n.e.c.</td></tr>
<tr><td rowspan="4">9</td><td rowspan="4">Pharmaceutical and chemical products</td><td>20</td><td>Basic Chemicals</td></tr>
<tr><td>21</td><td>Pharmaceutical Products</td></tr>
<tr><td>22</td><td>Fertilizers</td></tr>
<tr><td>23</td><td>Chemical Products and Preparations, n.e.c.</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">Other Nondurable Manufacturing</td><td>24</td><td>Plastics and Rubber</td></tr>
<tr><td>30</td><td>Textiles, Leather, and Articles of Textiles or Leather</td></tr>
<tr><td rowspan="4">11</td><td rowspan="4">Logs, Paper, Printed Material</td><td>25</td><td>Logs and Other Wood in the Rough</td></tr>
<tr><td>27</td><td>Pulp, Newsprint, Paper, and Paperboard</td></tr>
<tr><td>28</td><td>Paper or Paperboard Articles</td></tr>
<tr><td>29</td><td>Printed Products</td></tr>
<tr><td>12</td><td>Wood Products</td><td>26</td><td>Wood Products</td></tr>
<tr><td>13</td><td>Nonmetallic Mineral Products</td><td>31</td><td>Nonmetallic Mineral Products</td></tr>
<tr><td rowspan="9">14</td><td rowspan="9">Other Durable Manufactured Goods</td><td>32</td><td>Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes</td></tr>
<tr><td>33</td><td>Articles of Base Metal</td></tr>
<tr><td>34</td><td>Machinery</td></tr>
<tr><td>35</td><td>Electronic and Other Electrical Equipment and Components, and Office Equipment</td></tr>
<tr><td>36</td><td>Motorized and Other Vehicles (including parts)</td></tr>
<tr><td>37</td><td>Transportation Equipment, n.e.c.</td></tr>
<tr><td>38</td><td>Precision Instruments and Apparatus</td></tr>
<tr><td>39</td><td>Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs</td></tr>
<tr><td>40</td><td>Miscellaneous Manufactured Products</td></tr>
<tr><td>15</td><td>Waste and Scrap</td><td>41</td><td>Waste (recycled materials) does not included Municipal Solid Waste</td></tr>
<tr><td>16</td><td>Mixed Freight</td><td>43</td><td>Mixed Freight</td></tr>
</table>

(Source: Virginia DOT, Virginia Statewide Model.)

MODE CHOICE

Practitioners typically associate the direct acquisition of a commodity flow table with a less complex approach to analysis. Consistent with this working framework, analysts often assume that the existing mode share by origin, destination, and commodity remains the same in the future. This does not mean that overall mode share cannot appear to change in forecast years. Given that the mix of freight flows by origin, destination, and mode can change, this simplified constant mode share can result in the overall share of freight modes resulting from changes in the composition of the commodity flow table. Analysts use this assumption in forecasts of both TRANSEARCH and FAF; before assigning the commodity flow table to modal networks, analysts need to convert the multimodal table of freight flows into individual tables for each mode. Most transportation agencies have jurisdiction over highway networks, which trucks use to carry freight flows, but may not have a need for forecasts of O-D tables by non-highway modes.

With this simplified approach, modal thresholds based on commodity-specific target shares can serve as a basis for manual adjustment. O-D records where the existing mode share falls below a specified amount can be identified and adjusted upwards towards a target level as part of sensitivity tests. Analysts can use these adjusted flows to determine how changes in mode share can reflect through the system. In applying this approach, sometimes referred to as "market segmentation," analysts must strive to recognize that some commodities are virtually captive to using certain modes for a variety of reasons; in these cases, they should not make qualitative changes to mode shares, but recognize the captive market and consider other modes of forecasting. For example, gravel moves almost exclusively by rail or water and any shift away from these modes may not be realistic.

COMMODITY TONNAGE TO COMMODITY TRUCK CONVERSION

In many instances, it is not necessary to convert the commodity flow units, typically tons, to the flow units in an assignment, typically vehicles. Even if an analyst uses different assignment methods in peak and off-peak periods and the commodity flow is reported for a longer periods, it may still be useful to assign the commodity table without considering the time period, capacity restraint or flow units used in model networks. The freight assignment can display the preferred or 'best' routes for commodity flows independent of highway network times and costs.

It also may not be necessary to convert commodity flow tables by non-truck modes; those modal networks do not often share space with other non-freight uses or have well-developed modal assignment methods. For example, rail assignments to rail networks follow varying business rules dictated by track ownership and usage.

If the assignment considers the shared usage of a facility such as the highway network, analysts need to make the time period of the commodity flow O-D table consistent with the other O-D assigned tables. Commodity flow tables are typically reported as annual tonnage flows, while highway assignments are typically reported for vehicle flows on an average weekday. The commodity table, especially if TRANSEARCH is the source, may have been developed for a different time period, typically annual, than the time period used in a highway assignment for automobiles.

Analysts should convert tonnages to vehicles for highway assignments that consider shared usage by autos and trucks. TRANSEARCH reports flow by the truck's type of operation, such as truckloads by common carriers; this distinction is not useful for displaying total truck usage and performance, and analysts can combine these truck operations to a single "truck" mode for purposes of assignment and evaluating highway performance.

If TRANSEARCH reports flows by truck modal units, analysts can use these flows to reflect the total number of trucks and may not need to convert commodity flows. If an agency requires more detailed trip tables, analysts can compute the tons per truck (payload factors) according to the commodity groups discussed above. As an example, the tons per truck for the different commodity groups used in Wisconsin are shown in table 28.

Table 28. Tons per truck by Wisconsin Commodity Group.

Commodity Group		Tons per truck
1	Farm Products	16.02
2	Metallic Ores	25.38
3	Coal and Crude Petroleum	24.43
4	Nonmetallic Minerals	24.31
5	Misc. Nondurable Manufacturing	17.43
6	Food	22.89
7	Lumber	25.49
8	Paper	24.15
9	Chemicals	20.85
10	Petroleum Products	24.18
11	Rubber/Plastics	11.82
12	Misc. Durable Manufacturing	16.57
13	Clay, Concrete, Glass	16.05
14	Metal	24.80
15	Fabricated Metal Products	17.98
16	Machinery	13.42
17	Transportation Equipment	14.04
18	Waste	23.83
19	Misc. Freight Shipments	No trucks
20	Secondary Traffic and Drayage	19.63

(Source: Wisconsin Statewide Model.)

For Wisconsin, the average tons per truck over all commodities is 19.9 tons per truck, which is close to the standard assumption of 20 tons per combination tractor trailer trucks. This serves as confirmation that TRANSEARCH reports generally measure this type of truck.

ASSIGNMENT

The ability to assign commodity vehicle tables to a highway network depends on the routing ability of the highway network. The consideration of traffic other than freight trucks is not a requirement for assignment. In this case, analysts can use an acquired commodity table when there is not a corresponding O-D trip table for automobiles and non-freight trucks. However, a commodity table assigned directly to a highway network without the interaction of automobile traffic does not consider the congestion impacts generated by auto traffic.

To overcome this weakness and provide a more realistic context, analysts often combine commodity flow trip tables with a simplified auto trip table. Analysts assign the auto and truck trip tables to a highway assignment network to better reflect the overall congestion effects by auto and truck traffic on the highway network.

CHAPTER 9. TRIP-BASED FREIGHT FORECASTING

The trip-based freight forecasting method refers to trip-based models and assignment of freight and/or non-freight trucks to network links. Analysts apply these models to socioeconomic data to estimate the demand of freight and non-freight trucks, which analysts process; assign, usually as static traffic assignment (STA); and use to develop transportation network usage and performance.

Table 29 outlines the many methodological strengths and weakness of trip-based freight forecasting.

Table 29. Strengths and weakness of trip-based forecasting.

Elements		Remarks
Pros	Inclusion of local economic data and forecasts.	The tables of freight commodity flows and/or of non-freight trucks are prepared using methods that explicitly consider the forecast of the local economy. Trip rates are applied to local socioeconomic data and trading partners are forecasted using changes in local accessibility.
	Prediction of origin-destination (O-D) table flows and routing changes.	Under the trip-based method, both trip tables and assignments are calibrated to local conditions. Parameters estimated for a base year are applied to generate forecasts of usage and performance for future year routing choices that affect travel and system performance. Trips generated outside of the model boundaries are generalized to larger geographies (often States or districts) and are assigned to simplified sketch networks representing these geographies.
	Usage and performance for specific commodities and/or truck types.	Trip-based models are developed to forecast demand and to calculate usage and performance on specific modal networks (e.g., highways) by assigning demand for specific commodities and truck sizes. Stratified demand is estimated for specific commodities and/or truck sizes, and can be labeled and tracked through subsequent processes including the assignment of flows to network links.
Cons	Requirement for substantial data resources to estimate and apply models.	Trip-based models require detailed data that are disaggregated to smaller geographies. The development of these models reflect average conditions such as an average weekday, different time periods, and aggregation of individual data.
	Special treatment of intermediate stops.	Freight trips that are part of a larger tour and supply chain make intermediate stops. In trip-based methods, the intermediate stops are treated trip ends which makes it challenging to forecast the location and frequency of stops on a tour.

STATE OF PRACTICE IN TRIP-BASED FREIGHT MODELS

Trip-based freight models of highway demand should consist of two parts: forecasting the usage and performance of freight by all modes to determine the share of freight that moves by truck and forecasting the usage and performance for all other truck travel purposes.

Figure 28 outlines the development of trip-based freight models. These more traditional models start with the underlying zone system and networks, then analyze the existing freight data in five distinct steps:

- **Freight Trip Generation:** Generate freight tonnage data, where different parts of the study area produce and attract freight trips.
- **Freight Trip Distribution:** Estimate freight tonnage trip table to and from the study area zones by combining generated freight trips with travel impedances.
- **Freight Mode Choice:** Estimate the freight mode choice model with level of service and cost of travel by commodity and by freight mode serving each O-D market as the critical inputs.
- **Annual Tons to Daily Truck Conversion:** Convert the annual truck tonnage in each O-D market to daily trucks.
- **Highway Assignment:** Assign the daily trucks carrying freight to the highway network along with passenger traffic to represent traffic and congestion using the loaded highway networks.

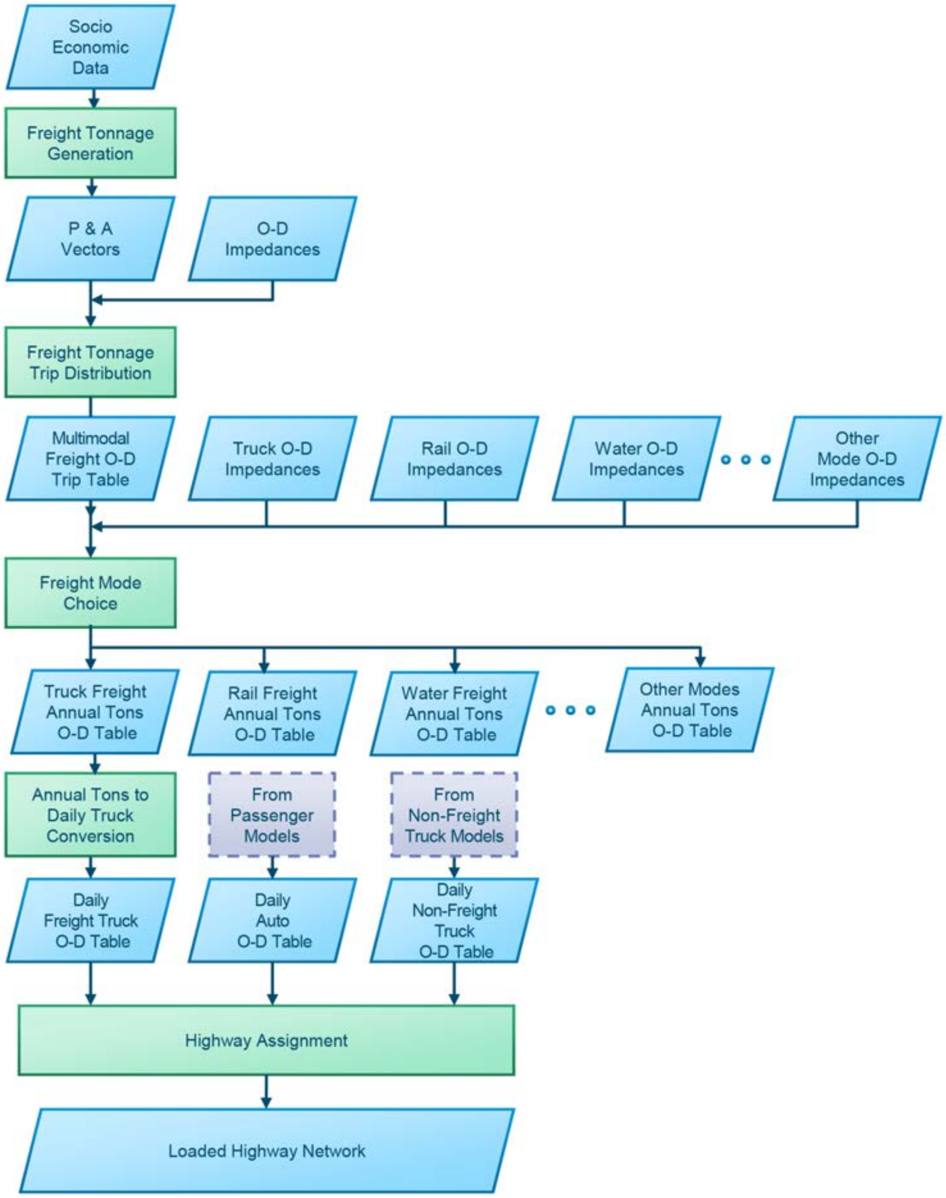

Figure 28. Flowchart. Trip-based freight forecasting method example.
(Source: Federal Highway Administration.)

Freight Network and Zone Structure

The controlling factors for freight demand occur over a larger geography than passenger demand. There are two methods to address these larger geographies:

- The zones for the freight model can cover a larger geography than the passenger model, with national or larger zones to account for international freight flows. These models can use a variable zone system with finer zones within the modeling region, large zones for the adjacent external areas, and larger zones for the rest of the country. The networks serving these external zones beyond the detailed model area are a simplified representation of the network. This method estimates the usage and performance in these external zones separately and varies with changes in usage and performance in the detailed model region.

- Analysts can calculate the freight usage and performance at external stations of the detailed region; for usage and performance beyond these external stations, analysts can compute from the connectors to these external stations and represent an average for the external areas served by these stations. This method will not change in response to changes in usage and performance within the detailed model region.

Freight Trip Generation

Chapter 3 discusses the many terms used in trip generation for freight: Freight generation (FG) as tons of goods; freight trip generation (FTG) in vehicles, typically trucks that transport tons; and service generation (SG) of trucks that are discussed later as non-freight trucks. This section discusses FTG. Additional information can be found in NCFRP Report 37 at: http://www.trb.org/NCFRP/NCFRPProjects.aspx.

Trip generation uses economic variables to forecast freight flows/vehicle flows to and from geographic areas using equations. Trip generation is a function of employment characteristics such as establishment size and type of economic activity. Analysts often develop freight trip generation equations locally using existing commodity flow tables or tables estimated from vehicle surveys. The outcome of freight trip generation is the quantity of a commodity originating from or destined to a particular geographic unit, most commonly a traffic analysis zone (TAZ), for a specified unit of time.

Trip generation models used in freight forecasting include a set of annual or daily trip generation rates or equations by commodity or commodity group. Analysts use these rates or equations to determine the commodity flows originating or terminating in geographic zones as a function of zonal population and/or industry sector employment data. Similar to passenger models, employment and population data are the essential input data required to compute freight trip generation.

The independent explanatory variables, such as employment and population, dictate the level of detail for the freight flows generated by a trip generation model. These variables may be available at a county or TAZ level. Travel demand models for passenger traffic usually use TAZ data. Practitioners can develop freight forecasting models at a TAZ level as long as the base and forecast year data at the required level of industry detail are available at that geographic unit. If these data are not available, aggregations of the TAZ geographies should be used.

Generally, analysts estimate two sets of regression equations: one for productions and one for attractions/consumption. Analysts develop regression equations for each commodity group or truck type. A commodity group or truck type is analogous to a “trip purpose” in passenger modeling.

The data used to estimate destination (attraction) regression models include tons by commodity class as the dependent variable. Independent variables include employment by industry type and population. Analysts treat outliers in the regression analysis, such as ports or intermodal terminals, like special generators in passenger models, as discussed later in this chapter.

In regression analysis, practitioners only use explanatory variables that they can vary themselves. Analysts can expect socioeconomic data for zones and aggregate forecasts of employment data to be available within the detailed model region. Detailed breakdowns of employment by industry within the model region are available for a base year (e.g., NAICS2 or NAICS3 employment). While forecasts may not be available at this detailed industrial breakdown, it is reasonable to assume that these same base year breakdowns will also apply in forecast years.

Analysts cannot expect forecasts of data inputs to be available for external zones beyond the detailed model region or for the external stations serving these external zones. For example, analysts can expect a freight model for Georgia to have data and forecasts for Georgia, but not data and forecasts for Chicago or for the I-75 external station at the Georgia-Tennessee State line serving those freight trips to Chicago.

Freight trip generation rates are similar to trip generation rates in passenger models and they are based on zonal averages. Rates may be expressed on average per employee and there may be considerable variation across industry classes. Small sample sizes can be an issue with small zones with limited observed economic activity. Analysts may apply freight trip generation rates to smaller zones, but they may need to estimate for aggregations of zones where more data are available.

Trip-based method estimation data should be available in trip-level format. The type of flow units available in the estimation data will dictate the flow units used in the regression. For multimodal freight models that include a mode choice step, analysts can sum the estimation data over all modes and present the estimation data in a multimodal flow unit, such as annual tons. Freight models limited to only the truck mode can use flow units expressed in tons carried by trucks.

As shown in figure 29 for productions and figure 30 for attractions, the demand for freight directly ties to economic activity, commonly represented by employment data and trends. These figures use the Wisconsin Statewide model to show the correlation between annual freight tonnage versus manufacturing employment for freight productions and total employment for freight attractions.

The outliers to the regression are most likely intermodal terminals where freight trips change modes, but the relatively low level of employment at that zone cannot provide explanatory power; of these examples, the Port of Superior is the outlier. Overall, the correlation between industry employment and tons of commodities appears significant both for tons produced in and for tons attracted to different areas of the State.

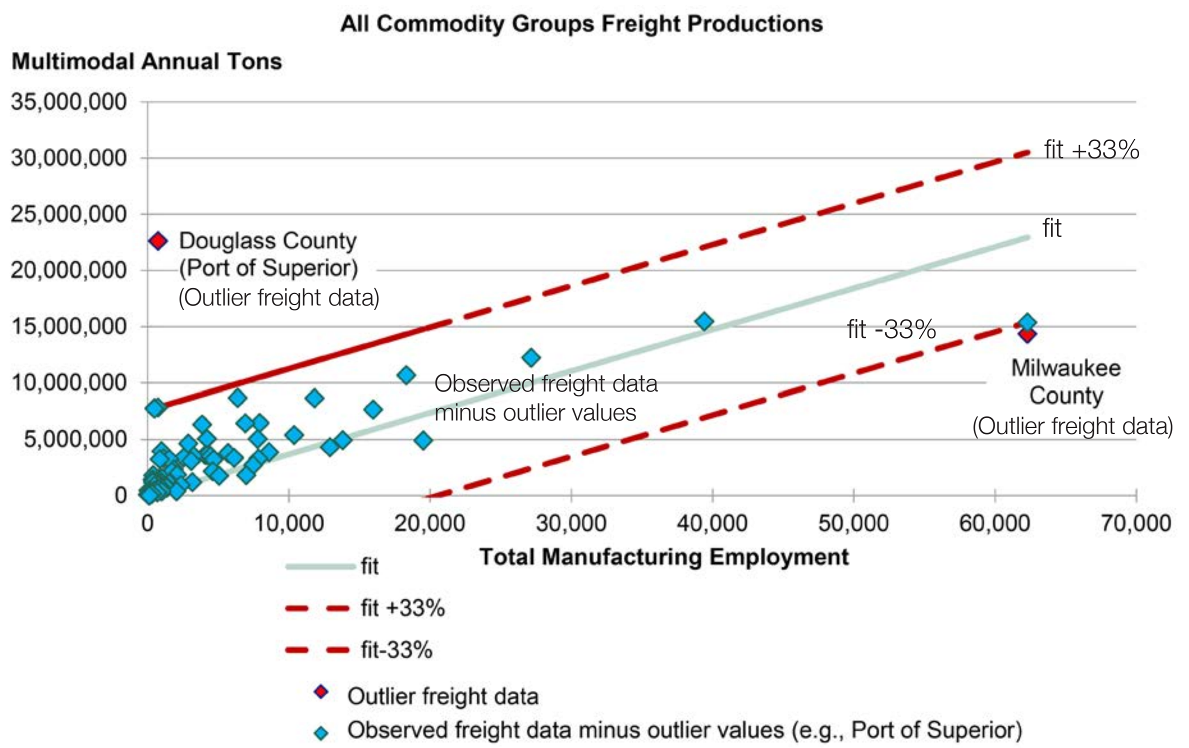

Figure 29. Graph. Freight productions versus manufacturing employment by Wisconsin County. (Source: Wisconsin Statewide Model.)

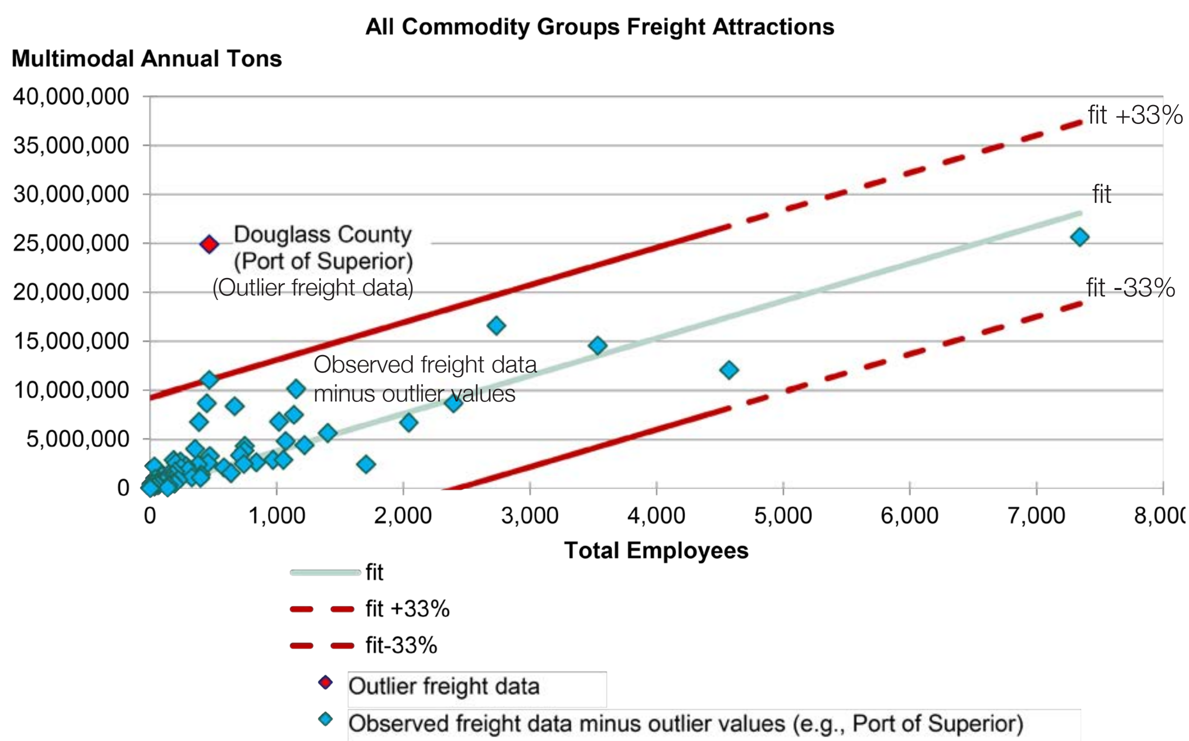

Figure 30. Graph. Freight attractions versus total employment by Wisconsin County. (Source: Wisconsin Statewide Mode.)

As discussed in chapter 8, it may be important to identify and distinguish among large freight flows for commodity groups that show significant variation within the study area. In such a case, the commodity groups of interest are treated differently with varying explanatory variables that result in unique production rates (e.g., tons per employee). Freight trip generations rates vary from region to region and from State to State, in part depending on differences specific to commodities that require local calibration.

To demonstrate these differences, table 30 shows the freight production rates developed for Statewide models in Texas, Virginia, and Wisconsin. An examination of table 30 reveals that the differences in each State's economy, commodity classifications, and explanatory variables create varied freight production rates for a variety of commodities.

The explanatory variables differ since the Wisconsin model relies mostly on industry-specific employment. In contrast, the Texas model uses productions as a direct input into the equation and both Texas and Virginia use total employment (instead of industry employment) as an explanatory variable for selected commodities.

Each State uses different classifications when addressing freight flows for commodities such as nonmetallic minerals, coal/petroleum, and manufacturing. This leads to estimates without direct comparisons. The agricultural category offers a good example of the differences:

- Texas uses the agriculture category in the Standard Transportation Commodity Classification (STCC) system (STCC 1, 8, and 9) and reports productions as a direct input.
- Wisconsin uses the same agriculture category as Texas, but estimates a production rate of 2,240 tons produced annually per employee in North American Industry Classification System (NAICS) code 11.
- Virginia uses the agricultural products category in the Standard Classification of Transported Goods (SCTG) system (SCTG 1 to 5) and estimates a much lower production rate of 1,145 tons produced annually per employee in NAICS code 11.

When examining the same sector, different assumptions lead to different rates for each of the Statewide models. These patterns are shown for commodities under food, lumber, and clay/concrete/glass. Although their definitions and explanatory variables are broadly consistent across the three Statewide models, the production rates for each commodity differ, reflecting the dissimilar structure of each State's economy.

Table 30. Freight production regression rates: annual tons.

Generic Commodity Group	Model Specific Commodity Group	STCC2s	SCTG2	Texas		Virginia		Wisconsin	
				NAICS Code	Coefficient	NAICS Code	Coefficient	NAICS Code	Coefficient
Agriculture products	Agriculture	01,08,09	–	Uses reported Ps directly as inputs		–	–	11	2,240.66
	Agriculture products	–	01-05	–	–	11	1,144.60	–	–
Coal and Crude Petroleum	Coal	11	–	Uses reported Ps directly as inputs		–	–	–	–
	Coal	–	15	–	–	2121	7,715.87	–	–
	Coal and Crude Petroleum	11, 13	–	–	–	–	–	212	585.60
Mining	Other Mining	10,13	–	Uses reported Ps directly as inputs		–	–	–	–
	Metallic ores	10	–	–	–	–	–	212	323.04
	Nonmetallic Minerals	14	–	212	7,083.72	–	–	212	13,422.60
				327	1,895.10				
	Stones, nonmetallic minerals, and metallic ores	–	10,13,14	–	–	Uses reported Ps directly as inputs	–	–	–
Sand and Gravel	Natural Sands	–	11	–	–	Uses reported Ps directly as inputs	–	–	–
	Gravel and Crushed Stone	–	12	–	–	Uses reported Ps directly as inputs	–	–	–

Table 30. Freight production regression rates: annual tons (continuation).

Generic Commodity Group	Model Specific Commodity Group	STCC2s	SCTG2	Texas		Virginia		Wisconsin	
				NAICS Code	Coefficient	NAICS Code	Coefficient	NAICS Code	Coefficient
Food	Food	20	–	311	665.81	–	–	311	288.48
	Grains, alcohol, and tobacco products	–	06-09	–	–	11	598.72	–	–
Consumer/ Non-Durable	Consumer Manufacturing	21, 22, 23, 31	–	31	1.49	–	–	–	–
	Nondurable Manufacturing	27, 30	–	32	34.26	–	–	–	–
	Misc. Nondurable Manufacturing	19, 21, 22, 23, 25, 27, 31	–	–	–	–	–	31 and 32 n.e.c.	71.47
	Other Nondurable Manufactured Goods	–	24,30	–	–	31 and 32 n.e.c.	21.97	–	–
Wood	Lumber	24	–	321	528.09	–	–	321	444.52
	Wood Products	–	26	–	–	321	140.63	–	–
Durable Manufacturing	Durable Manufacturing	19, 25, 34, 35, 36, 37, 38, 39	–	33	67.69	–	–	–	–
	Durable Manufactured Goods	–	32-40	–	–	33 n.e.c.	30.83	–	–
	Misc. Durable Manufacturing	36, 38, 39	–	–	–	–	–	33 n.e.c.	21.50
	Rubber/Plastics	30	–	–	–	–	–	326	84.85

Table 30. Freight production regression rates: annual tons (continuation).

Generic Commodity Group	Model Specific Commodity Group	STCC2s	SCTG2	Texas		Virginia		Wisconsin	
				NAICS Code	Coefficient	NAICS Code	Coefficient	NAICS Code	Coefficient
Paper	Paper	26	–	322	443.87	–	–	322	151.83
	Logs, paper, printed material	–	25, 27, 28, 29	–	–	Uses reported Ps directly as inputs	–	–	–
Chemicals	Chemicals	28	–	325	3,524.17	–	–	325	245.55
	Pharmaceutical and chemical products	–	20, 21, 22, 23	–	–	325	287.22	–	–
Petroleum Products	Petroleum	29	–	324	21,270.18	–	–	324	5,098.35
	Fuel products	–	17,18	–	–	324	2,753.60	–	–
	Coal and Petroleum Products, not elsewhere classified (n.e.c.)	–	19	–	–	324	488.14	–	–
Nonmetallic Mineral Products	Clay, Concrete, Glass	32	–	327	3,524.17	–	–	327	1,422.89
	Nonmetallic Mineral Products	–	31	–	–	327	919.49	–	–
Primary Metal	Primary Metal	33	–	331	537.60	–	–	331	322.29
				332	96.96				
Fabricated Metal Products	Fabricated Metal Products	34	–	–	–	–	–	332	59.04
Machinery	Machinery	35	–	–	–	–	–	333	35.76

Table 30. Freight production regression rates: annual tons (continuation).

Generic Commodity Group	Model Specific Commodity Group	STCC2s	SCTG2	Texas		Virginia		Wisconsin	
				NAICS Code	Coefficient	NAICS Code	Coefficient	NAICS Code	Coefficient
Transportation Equipment	Transportation Equipment	37	–	–	–	–	–	336	72.57
Waste and Mixed Freight	Secondary and Misc. Mixed	50, 40-49	–	TotEMP	26.37	–	–	–	–
	Waste and Scrap	–	41	–	–	TotEMP	2.82	–	–
	Mixed Freight	–	43	–	–	TotEMP	4.84	–	–
	Waste	40	–	–	–	–	–	TotEMP	2.73
	Secondary Traffic and Drayage	50	–	–	–	–	–	TotEMP	3.80

(Source: Texas, Virginia, and Wisconsin Departments of Transportation.)

Table 31 shows the corresponding freight attraction rates developed for these same three Statewide freight models, and the differences identified in table 31 share similarities with the differences in freight productions in table 30. For instance:

- Total employment is the key explanatory variable for most commodities, models use the reported freight attractions directly as an input and others use total population as an explanatory variable.
- Each Statewide model uses different classification systems (e.g., STCC, SCTG) when addressing freight flows for commodities such as agriculture, nonmetallic minerals, and manufacturing. These differences make the freight trip attraction rates impossible to compare across geographies.

In summary, analysts should estimate freight generation rates for both the production and the attraction ends using data specific to the study area. In cases where the freight production and attraction rates need to be transferred, analysts should exercise caution and only transfer rates from other regions that have similar economies, transport similar commodities, and use the same conventions to identify and group commodities. Testing the transferred parameters is critical to ensure that the equations apply to the new study area and produce reasonable estimates for each commodity.

Table 31. Freight attraction regression rates: annual tons.

Generic Commodity Group	Model Specific Commodity Group	STCC2s	SCTG2s	Texas NAICS Code	Texas Coefficient	Virginia NAICS Code	Virginia Coefficient	Wisconsin NAICS Code	Wisconsin Coefficient
Agriculture products	Agriculture	01,08,09	–	TOTPOP	2.06	–	–	424	503.91
	Agriculture products	–	01-05	–	–	424	374.50	–	–
Coal and Crude Petroleum	Coal	11	–	Uses reported Attractions directly as inputs		–	–	–	–
	Coal	–	15	–	–	221	372.61	–	–
	Coal and Crude Petroleum	11, 13	–	–	–	–	–	221	1,980.31
Mining	Mining	10,13	–	Uses reported Attractions directly as inputs		–	–	–	–
	Metallic ores	10	–	–	–	–	–	42	3.24
	Nonmetallic Minerals	14	–	TOTPOP	7.79	–	–	42	343.34
	Stones, nonmetallic minerals, and metallic ores	–	10, 13, 14	–	–	TOTPOP	0.42	–	–
Sand and Gravel	Natural Sands	–	11	–	–	TOTPOP	0.77	–	–
	Gravel and Crushed Stone	–	12	–	–	TOTPOP	6.78	–	–
Food	Food	20	–	TOTPOP	2.26	–	–	42	297.55
				42	20.69				
	Grains, alcohol, and tobacco products	–	06-09	–	–	424	187.53	–	–

Table 31. Freight attraction regression rates: annual tons (continuation).

Generic Commodity Group	Model Specific Commodity Group	STCC2s	SCTG2s	Texas		Virginia		Wisconsin	
				NAICS Code	Coefficient	NAICS Code	Coefficient	NAICS Code	Coefficient
Consumer/ Non-Durable	Consumer Manufacturing	21,22,23,31	–	TOTPOP	0.01	–	–	–	–
				42	4.30				
	Nondurable Manufacturing	27, 30	–	TOTPOP	0.21	–	–	–	–
				42	12.70				
	Misc. Nondurable Manufacturing	19, 21, 22, 23, 25, 27, 31	–	–	–	–	–	42	12.76
	Other Nondurable Manufactured Goods	–	24, 30	–	–	TotEMP	0.86	–	–
Wood Products	Lumber	24	–	TOTPOP	0.37	–	–	42	41.39
				42	15.88				
	Wood Products	–	26	–	–	424	55.78	–	–
Durable Manufacturing	Durable Manufacturing	19, 25, 34, 35, 36, 37, 38, 39	–	TOTPOP	0.82	–	–	–	–
				42	39.38				
	Durable Manufactured Goods	–	32-40	–	–	TotEMP	3.17	–	–
	Misc. Durable Manufacturing	36, 38, 39	–	–	–	–	–	42	17.04
	Rubber/Plastics	30	–	–	–	–	–	42	12.52
Paper	Paper	26	–	TOTPOP	0.25	–	–	42	31.35
				42	8.69				
	Logs, paper, printed material	–	25, 27, 28, 29	–	–	322	38.83	–	–
						TotEMP	0.92		
Chemicals	Chemicals	28	–	325	2,302.72	–	–	42	44.82
	Pharmaceutical and chemical products	–	20, 21, 22, 23	–	–	424	90.97	–	–

Table 31. Freight attraction regression rates: annual tons (continuation).

Generic Commodity Group	Model Specific Commodity Group	STCC2s	SCTG2s	Texas NAICS Code	Texas Coefficient	Virginia NAICS Code	Virginia Coefficient	Wisconsin NAICS Code	Wisconsin Coefficient
Petroleum Products	Petroleum	29	–	324	7,022.36	–	–	42	95.35
				TOTPOP	5.50				
	Fuel products	–	17, 18	–	–	TOTPOP	1.25	–	–
	Coal and Petroleum Products, n.e.c.	–	19	–	–	TOTPOP	0.95	–	–
Nonmetallic Mineral Products	Clay, Concrete, Glass	32	–	TOTPOP	1.96	–	–	42	96.98
				42	140.45				
	Nonmetallic Mineral Products	–	31	–	–	TOTPOP	1.93	–	–
Primary Metal	Primary Metal	33	–	TOTPOP	0.37	–	–	42	48.07
				42	21.98				
Fabricated Metal Products	Fabricated Metal Products	34	–	–	–	–	–	423	36.71
Machinery	Machinery	35	–	–	–	–	–	424	34.65
Transportation Equipment	Transportation Equipment	37	–	–	–	–	–	423	21.06
Waste and Mixed Freight	Secondary and Misc. Mixed Freight	50, 40-49	–	All	17.01	–	–	–	–
	Waste and Scrap	–	41	–	–	424	87.99	–	–
	Mixed Freight	–	43	–	–	TOTPOP	3.24	–	–
	Waste	40	–	–	–	–	–	42	51.17
	Secondary Traffic and Drayage	50	–	–	–	–	–	42	90.31

(Source: Texas, Virginia, and Wisconsin Departments of Transportation.)

Practitioners estimate trip generation rates for a base year and apply them to the forecast years. Productivity changes associated with the explanatory variable (e.g., changes in tons per NAICS employee) may be included in forecasting models, but the values for any such productivity changes should be derived from other sources.

Although analysts often estimate freight generation rates as a series of linear regressions for individual commodity groups, more sophisticated models can be developed. Freight trip generation may include the productions or attractions for other commodity groups. For example, the explanatory variables to produce automobiles in a zone may include the employment in automobile manufacturing (NAICS 336) and the forecasted attractions for primary metals to that zone.

Analysts must estimate these structural equations simultaneously, not individually, for all commodity groups using specialized programs.[12] In the case of 15 production and 15 attraction equations for 15 commodity groups, linear regression can solve each of these 30 equations independently. Analysts cannot use the explanatory variable in one equation as a dependent variable in another equation. In contrast, structural trip generation models solve for all of these equations simultaneously and allow productions and attractions for one commodity to be an explanatory variable in the equations for a different commodity.

Analysts can forecast the internal productions and attractions of freight using the rates discussed above; however, they cannot forecast the productions and attractions external to the region in the same manner. This document recommends that analysts use external estimation data to determine the productions and attractions by commodity group in external regions using the following guidelines:

- If the estimation data include external zones and the freight model also uses external zones, analysts may use the estimation data to develop the productions and attractions for these same external zones.

- If the estimation data use external zones beyond a model boundary but the freight model uses external stations at those model boundaries through which freight must travel to or from these zones, analysts can assign the estimation data to a network that is geographically consistent with the estimation data.

- If the assignment is windowed to a subarea at the study area border that includes the external stations and the estimation data. Analysts repeat this same process with the forecast data to compute growth rates between the base and forecast years of the estimation data.

- If the estimation data includes pass-through traffic, analysts can use the processes described above for external traffic to develop external-external traffic, but only for the modes that they will use in their assignment.

[12] Ranaiefar, F., et al, "Geographic Scalability and Supply Chain Elasticity of a Structural Commodity Generation Model Using Public Data", Institute of Transportation Studies, University of California, Irvine; Irvine, October, 2012.

Outliers

Practitioners should treat outliers in the regression process in a manner similar to special generators in passenger models. Regression outliers include cases where the observed freight tonnage exceeds current employment and cases where employment exceeds the tonnage. Examples of how we treat such two outlier cases are discussed below.

Tonnage Exceeds Employment: In these cases, the tonnage of a commodity is not proportional to the underlying industry employment that the analyst used as an explanatory variable. Highly automated facilities, such as auto manufacturing plants, have far fewer employees than the tonnage of freight produced. For example, the Wisconsin Statewide freight model identified the former Janesville automobile manufacturing facility as the reason that Rock County was an outlier in its regression equations.

There are also cases where tonnage of a commodity exists without the associated employment. Ports or transfer facilities can appear to generate tonnages of commodities that are not actually "produced" at the facility. One example is the Port of Baltimore, which imports significant tonnages of automobiles but does not have the automobile manufacturing employment associated with this "production" of automobiles.

Employment Exceeds Tonnage: In these cases, the industry employment associated with a commodity is not proportional to the tonnage produced. An example of this is the oil and gas industry, where the site of corporate headquarters may have many of employees in that industry, but these office jobs do not actually produce tons of freight.

In cases where employment exists but there are no observed tonnages, a different employment industry may be generating the tonnages. An example of this is in northern Florida, where the observable tonnages of turpentine and chemical products are generated by the wood products industry and not the chemical industry identified as the explanatory variable.

Effective forecasting requires local knowledge of the study area to understand the outliers identified during the regression process. Analysts may generate rates for the outliers from site-specific survey data to allow the outlier to be forecasted. If rates are not developed for the outliers, then the identified outlier values should be held constant during forecasts.

Freight Trip Distribution

The distribution of freight from zones of production to zones of attraction in most trip-based methods use a standard gravity model, where the friction factor, the difficulty of travel, is shown figure 31:

$$FF_{\mathrm{cij}} = \exp(-(1/ATL_{\mathrm{c}}) * dd_{\mathrm{ij}})$$

Figure 31. Equation. Friction factor equation.

Where:

FF_{cij} = Friction factor for O-D pair ij and commodity group *c*.

ATL_c = Average travel length for commodity group *c*.

dd_{ij} = Distance between O-D pair *ij*.

The individual O-D distances correlate with shipping costs, but the average distance is mostly related to the region's actual location relative to its trading partners. For this reason, even when regions trade the same commodity group, the average trip lengths may differ. Table 32 illustrates this: for the chemical commodity group in trip-based models in Texas and Wisconsin, the average trip length calculated for Texas is 2.4 (1,322.9 miles/574.2 miles) times longer than the average distance for Wisconsin.

As noted previously, analysts can only transfer trip generation rates between regions with similar economic structures. Transferring distribution factors, such as average trip lengths, is more restrictive and requires more caution. Not only should the economies be similar, but the location with respect to its trading partners must be similar as well. Given the very low likelihood of comparable trip lengths and economic interactions, analysts should not transfer average freight trip lengths in the absence of additional insights from local data.

Estimations that use reported data typically include the distance between each pair of origin and destination zones. If the estimation does not report distances between zones, they can be derived from the skims between O-Ds reported by the Oak Ridge National Laboratory's Center for Transportation Analysis at https://cta.ornl.gov/transnet/SkimTree.htm.

Table 32. Freight trip distribution average trip lengths.

Average (Multimodal) Trip Length (ATL)				Texas	Virginia	Wisconsin
Generic Commodity Group	**Model Specific Commodity Group**	**STCC2s**	**SCTG2**	**ATL Miles**	**ATL Miles**	**ATL Miles**
Agriculture products	Agriculture	01,08,09	–	1,539.2	–	251.0
	Agriculture products	–	01-05	–	373.2	–
Coal and Crude Petroleum	Coal	11	–	1,176.0	–	–
	Coal	–	15	–	477.8	–
	Coal and Crude Petroleum	11, 13	–	–	–	916.5

Table 32. Freight trip distribution average trip lengths (continuation).

Average (Multimodal) Trip Length (ATL)				Texas	Virginia	Wisconsin
Generic Commodity Group	**Model Specific Commodity Group**	**STCC2s**	**SCTG2**	**ATL Miles**	**ATL Miles**	**ATL Miles**
Mining	Mining	10,13	–	888.0	–	–
	Metallic ores	10	–	–	–	444.1
	Nonmetallic Minerals	14	–	670.3	–	321.3
	Stones, nonmetallic minerals, and metallic ores	–	10,13,14	–	359.9	–
Sand and Gravel	Natural Sands	–	11	–	300.7	–
	Gravel and Crushed Stone	–	12	–	241.2	–
Food	Food	20	–	1,715.9	–	485.3
	Grains, alcohol, and tobacco products	–	06-09	–	466.6	–
Consumer/ Non-Durable	Consumer Manufacturing	21, 22, 23, 31	–	2,174.9	–	–
	Nondurable Manufacturing	27, 30	–	1,837.7	–	–
	Misc. Nondurable Manufacturing	19, 21, 22, 23, 25, 27, 31	–	–	–	676.2
	Other Nondurable Manufactured Goods	–	24,30	–	612.6	–
Wood Products	Lumber	24	–	1,437.5	–	447.6
	Wood Products	–	26	–	399.0	–
Durable Manufacturing	Durable Manufacturing	19, 25, 34, 35, 36, 37, 38, 39	–	1,828.4	–	–
	Durable Manufactured Goods	–	32-40	–	527.1	–
	Misc. Durable Manufacturing	36, 38, 39	–	–	–	694.3
	Rubber/Plastics	30	–	–	–	564.3
Paper	Paper	26	–	1,463.5	–	640.5
	Logs, paper, printed material	–	25,27, 28, 29	–	392.0	–
Chemicals	Chemicals	28	–	1,322.9	–	574.2
	Pharmaceutical and chemical products	–	20, 21, 22, 23	–	625.3	–

Table 32. Freight trip distribution average trip lengths (continuation).

Average (Multimodal) Trip Length (ATL)				Texas	Virginia	Wisconsin
Generic Commodity Group	**Model Specific Commodity Group**	**STCC2s**	**SCTG2**	**ATL Miles**	**ATL Miles**	**ATL Miles**
Petroleum Products	Petroleum	29	–	935.4	–	241.5
	Fuel products	–	17,18	–	135.3	–
	Coal and Petroleum Products, (n.e.c.)	–	19	–	316.4	–
Nonmetallic Mineral Products	Clay, Concrete, Glass	32	–	1,414.2	–	282.8
	Nonmetallic Mineral Products	–	31	–	220.5	–
Primary Metal	Primary Metal	33	–	1,661.7	–	480.4
Fabricated Metal Products	Fabricated Metal Products	34	–	–	–	386.8
Machinery	Machinery	35	–	–	–	544.2
Transportation Equipment	Transportation Equipment	37	–	–	–	500.9
Waste and Mixed Freight	Secondary and Misc. Mixed	50, 40-49	–	1,902.9	–	–
	Waste and Scrap	–	41	–	269.3	–
	Mixed Freight	–	43	–	380.5	–
	Waste	40	–	–	–	320.8
	Secondary Traffic and Drayage	50	–	–	–	338.7

(Source: Texas, Virginia, and Wisconsin Departments of Transportation.)

Freight Mode Choice

The standard method for estimating future year mode shares is the development of a logit model of freight mode choice based on the utilities of the competing freight modes. The coefficients of the utility equations include sensitivity to different travel time components and costs of travel; analysts typically develop these by fitting the observed mode shares to the utilities of competing freight modes. Although mode choice models are often estimated for passenger travel, the propriety nature and cost of information make mode choice models in freight travel difficult to estimate.

In the absence of a fully estimated freight mode choice model, an incremental formulation of the logit choice model provides an option to assess changes in freight mode market shares. This approach utilizes base and future year model inputs for network level of service, other explanatory economic variables, and observed market shares by mode for the base year. It also requires an estimate of the sensitivity to travel time and cost across competing freight modes.

This approach can help analysts predict changes to the relative utility of a freight mode and its corresponding market share; they can apply the incremental formulation to each commodity group using changes in the modal utility in any O-D market resulting from changes in costs and/or travel times for that market. Analysts often use incremental logit formulation in passenger travel demand forecasting and is well-suited to this application.

Figure 32 details the incremental logit model formulation.

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

Figure 32. Equation. Incremental Logit Model Formulation.

Where:

S'*ijm* = New share of the flows carried by mode *m* between zone *i* and zone *j*.

Sijm = Existing share of the flows carried by mode *m* between zone *i* and zone *j*.

Uijm = Utility from *i* to *j* of mode *m* among all modes *m*, which in turn is stated as:

$$Uijm = Modal\ Constant\ m + bv * ExplVarv_{ijm}$$

Where:

bv = Coefficient for *ExplVar v* (e.g., travel time).

$ExplVarv_{ijm}$ = Explanatory Variable *v* (e.g., travel time) for mode *m* between *i* and *j*.

In the incremental logit application, analysts need to specify utility equations only for modes where they expect the utility to change. In proposed freight applications, only truck and rail modes have utilities expected to change; the utilities for air and water modes typically do not change. Incremental logit mode choice does not capture changes when a new service is introduced.

Some commodity and origin-destination markets do not have existing shipments in the estimation database, making an incremental application impossible. In such cases, analysts can apply a logit mode choice model (if available) to the freight forecasts using the average mode-specific shares estimated from the estimation database.

Existing Mode Shares

In the absence of an estimated mode choice model or an incremental logit formulation, analysts can focus on the existing market share by each competing mode. Analysts can develop the required table of existing mode shares directly from the table of modal freight tonnage flows by origin-destination market, commodity group, and mode. This table calculates the percent of tons transported by a freight mode for a given origin-destination market and commodity group. An example of this is provided in table 33.

Table 33. 2012 FAF modes shares by tonnage.

2012 FAF Tons	Truck	Rail	Water	Pipeline	Multiple Modes and Mail	No Domestic Mode	Other and Unknown	Air (include Truck-Air)	Grand Total
Alcoholic beverages	87%	8%	0%	0%	4.7%	0.0%	0.1%	0.0%	100%
Animal feed	89%	7%	0%	0%	2.8%	0.0%	0.0%	0.1%	100%
Articles-base metal	88%	5%	1%	0%	6.0%	0.0%	0.0%	0.2%	100%
Base metals	81%	13%	1%	0%	4.5%	0.0%	0.0%	0.0%	100%
Basic chemicals	50%	27%	13%	8%	1.9%	0.0%	0.0%	0.1%	100%
Building stone	95%	3%	0%	0%	1.7%	0.0%	0.0%	0.0%	100%
Cereal grains	77%	19%	3%	0%	1.7%	0.0%	0.0%	0.0%	100%
Chemical prods.	88%	6%	1%	0%	4.6%	0.0%	0.0%	0.2%	100%
Coal	22%	64%	6%	0%	5.0%	0.0%	3.3%	0.0%	100%
Coal-n.e.c.	16%	2%	2%	79%	0.2%	0.0%	0.0%	0.0%	100%
Crude petroleum	2%	4%	8%	51%	0.0%	34.6%	0.0%	0.0%	100%
Electronics	85%	1%	1%	0%	11.2%	0.0%	0.0%	1.7%	100%
Fertilizers	59%	30%	6%	1%	3.5%	0.0%	0.2%	0.0%	100%
Fuel oils	52%	2%	16%	29%	1.2%	0.0%	0.0%	0.0%	100%
Furniture	93%	1%	1%	0%	5.4%	0.0%	0.0%	0.1%	100%
Gasoline	56%	2%	7%	34%	1.1%	0.0%	0.0%	0.0%	100%
Gravel	91%	4%	3%	0%	2.0%	0.0%	0.0%	0.0%	100%
Live animals/fish	100%	0%	0%	0%	0.0%	0.0%	0.0%	0.0%	100%
Logs	99%	0%	0%	0%	0.1%	0.0%	0.0%	0.0%	100%
Machinery	88%	2%	1%	0%	8.4%	0.0%	0.0%	0.6%	100%
Meat/seafood	97%	1%	1%	0%	1.4%	0.0%	0.0%	0.2%	100%
Metallic ores	23%	53%	12%	0%	11.8%	0.0%	0.0%	0.0%	100%
Milled grain prods.	82%	13%	1%	0%	3.6%	0.0%	0.0%	0.0%	100%
Misc. mfg. prods.	92%	1%	0%	0%	6.8%	0.0%	0.1%	0.2%	100%

Table 33. 2012 FAF modes shares by tonnage (continuation).

2012 FAF Tons	Truck	Rail	Water	Pipeline	Multiple Modes and Mail	No Domestic Mode	Other and Unknown	Air (include Truck-Air)	Grand Total
Mixed freight	98%	0%	0%	0%	1.4%	0.0%	0.6%	0.0%	100%
Motorized vehicles	82%	8%	1%	0%	9.2%	0.0%	0.1%	0.3%	100%
Natural sands	94%	4%	1%	0%	1.1%	0.0%	0.0%	0.0%	100%
Newsprint/paper	73%	20%	1%	0%	5.7%	0.0%	0.0%	0.0%	100%
Nonmetal min. prods.	93%	4%	1%	0%	1.9%	0.0%	0.0%	0.0%	100%
Nonmetallic minerals	71%	15%	9%	1%	3.2%	0.0%	0.0%	0.0%	100%
Other agricultural prods.	86%	5%	3%	0%	5.5%	0.0%	0.0%	0.0%	100%
Other foodstuffs	89%	7%	0%	0%	3.1%	0.0%	0.0%	0.0%	100%
Paper articles	94%	4%	0%	0%	2.1%	0.0%	0.0%	0.0%	100%
Pharmaceuticals	79%	3%	2%	0%	16.0%	0.0%	0.0%	1.0%	100%
Plastics/rubber	67%	25%	1%	0%	7.4%	0.0%	0.0%	0.1%	100%
Precision instruments	61%	1%	1%	0%	31.3%	0.0%	0.1%	4.7%	100%
Printed prods.	91%	1%	0%	0%	7.4%	0.0%	0.0%	0.3%	100%
Textiles/leather	83%	1%	1%	0%	13.9%	0.0%	0.0%	0.7%	100%
Tobacco prods.	97%	1%	1%	0%	1.8%	0.0%	0.1%	0.1%	100%
Transport equip.	47%	17%	11%	0%	9.0%	0.0%	5.6%	9.5%	100%
Unknown	35%	65%	0%	0%	0.0%	0.0%	0.0%	0.0%	100%
Waste/scrap	91%	5%	2%	0%	2.7%	0.0%	0.0%	0.0%	100%
Wood prods.	90%	7%	0%	0%	3.3%	0.0%	0.0%	0.0%	100%
All Commodities	63%	11%	4%	18%	2.5%	1.8%	0.2%	0.0%	100%

(Source: FAF4.)

Mode shares derived from the estimation data are even less suitable for transfer between regions. To transfer freight generation rates, the economies of the regions should be similar; to transfer trip distribution parameters, both the economies and the location with respect to trading partners should be similar. Transferring mode shares and utilities requires both previous circumstances and the modes available to those trading partners should be similar. Because of this incompatibility, this report does not present a table of mode shares.

Conversion of Tons by Truck to Number of Trucks

The outputs from the mode choice step are tables of tons of freight by commodity group and mode. Analysts can assign the trip tables by mode to the respective modal networks. Often only the freight truck trip table is assigned to the modal (highway) network. Assigning truck freight tables to a network requires that the analyst expresses the tables in the same units and time periods as the other non-freight vehicles assigned to the network. Analysts typically convert annual tons to average weekday freight trucks for use in highway assignment. The annual conversion factor reported in National Cooperative Freight Research Program (NCFRP) Report 8 is 296 equivalent average weekdays per year based on observed truck volumes. This is roughly equivalent to five weekdays plus half of an equivalent weekday for each weekend day for 52 weeks less 10 holidays.

Analysts can convert daily tons to daily trucks using commodity group-specific payload or truck equivalency factors. The caution on transferring rates and parameters from other steps does not typically apply to payload factors; as shown in table 34, payload factors are more similar across regions for commodity groups and transferable. If the estimation data include both trucks and tons for each flow record, analysts can develop region-specific tables for tons per truck. If analysts cannot develop payload factors from the estimation data, they can review other sources, such as the U.S. Vehicle Inventory and Use Survey (VIUS) or Weigh in Motion (WIM) data, to develop these conversion factors.

Table 34. Freight truck tons per truck parameters.

Truck Payloads				Texas	Virginia	Wisconsin
Generic Commodity Group	**Commodity Group**	**STCC2s**	**SCTG2**	**Tons per Truck**	**Tons per Truck**	**Tons per Truck**
Agriculture products	Agriculture	01,08,09	–	16.88	–	16.02
	Agriculture products	–	01-05	–	19.36	–
Coal and Crude Petroleum	Coal	11	–	24.81	–	–
	Coal	–	15	–	24.81	–
	Coal and Crude Petroleum	11, 13	–	–	–	24.43
Mining	Mining	10,13	–	23.01	–	–
	Metallic ores	10	–	–	–	25.38
	Nonmetallic Minerals	14	–	24.31	–	24.31

Table 34. Freight truck tons per truck parameters (continuation).

Truck Payloads				Texas	Virginia	Wisconsin
Generic Commodity Group	**Commodity Group**	**STCC2s**	**SCTG2**	**Tons per Truck**	**Tons per Truck**	**Tons per Truck**
Sand and Gravel	Stones, nonmetallic minerals, and metallic ores	–	10,13,14	–	24.29	–
	Natural Sands	–	11	–	24.31	–
	Gravel and Crushed Stone	–	12	–	24.31	–
Food	Food	20	–	22.89	–	22.89
	Grains, alcohol, and tobacco products	–	06-09	–	21.92	–
Consumer/ Non-Durable	Consumer Manufacturing	21, 22, 23, 31	–	17.85	–	–
	Nondurable Manufacturing	27, 30	–	13.64	–	–
	Misc. Nondurable Manufacturing	19, 21, 22, 23, 25, 27, 31	–	–	–	17.43
	Other Nondurable Manufactured Goods	–	24, 30	–	15.71	–
Wood Products	Lumber	24	–	25.50	–	25.49
	Wood Products	–	26		25.47	–
Durable Manufacturing	Durable Manufacturing	19, 25, 34, 35, 36, 37, 38, 39	–	15.55	–	–
	Durable Manufactured Goods	–	32-40	–	17.42	–
	Misc. Durable Manufacturing	36, 38, 39	–	–	–	16.57
	Rubber/Plastics	30	–	–	–	11.82
Paper	Paper	26	–	24.18	–	24.15
	Logs, paper, printed material	–	25, 27, 28, 29	–	23.63	–
Chemicals	Chemicals	28		20.21	–	20.85
	Pharmaceutical and chemical products	–	20, 21, 22, 23	–	20.99	–
Petroleum Products	Petroleum	29		24.16	–	24.18
	Fuel products	–	17,18	–	24.41	–
	Coal and Petroleum Products, n.e.c.	–	19	–	23.62	–

Table 34. Freight truck tons per truck parameters (continuation).

Truck Payloads				Texas	Virginia	Wisconsin
Generic Commodity Group	**Commodity Group**	**STCC2s**	**SCTG2**	**Tons per Truck**	**Tons per Truck**	**Tons per Truck**
Nonmetallic Mineral Products	Clay, Concrete, Glass	32	–	15.88	–	16.05
	Nonmetallic Mineral Products	–	31	–	16.26	–
Primary Metal	Primary Metal	33	–	24.91	–	24.8
Fabricated Metal Products	Fabricated Metal Products	34	–	–	–	17.98
Machinery	Machinery	35	–	–	–	13.42
Transportation Equipment	Transportation Equipment	37	–	–	–	14.04
Waste and Mixed Freight	Secondary and Misc. Mixed	50, 40-49	–	19.62	–	–
	Waste and Scrap	–	41	–	23.92	–
	Mixed Freight	–	43	–	20.13	–
	Waste	40	–	–	–	23.83
	Secondary Traffic and Drayage	50	–	–	–	19.63

(Source: Texas, Virginia, and Wisconsin Statewide Models.)

Assignment

The process of allocating truck trip tables or freight-related vehicular flows to a transportation network is known as traffic assignment or network assignment. There are many types of assignments that depend on several factors such as level of geography, number of modes of travel, type of study and planning application, data limitations, and computational power.

Freight assignments can be applied for any trip table of freight by mode to its respective modal network, but analysts mostly prepare assignments for freight trucks on highway networks. The assignment process may vary, but trip-based freight models typically use a static traffic assignment. Analysts can prepare the assignments concurrently with non-freight and auto assignments to properly capture total traffic and network congestion levels. The assignment of these tables may use truck prohibitions on certain network facilities and account for the different impact of trucks on congestion by requiring different volume delay functions.

Key issues that arise from developing truck trip assignment methodologies are:

- **Time-of-Day Factors—**These distribution factors allocate truck trips to each of the modeling time periods; analysts can examine these factors using recent data.

- **Roadway Capacity and Congested Speeds—**A single truck uses more of the available capacity of a roadway than an automobile. Passenger car equivalent (PCE) factors are required to convert the truck flows to PCEs prior to the assignment process.

- **Truck Values of Time—**Values of time are important considerations when tolling and generalized cost functions are used in assignment.

- **Volume-Delay Functions—**Analysts use these functions to estimate average speeds as a function of volume and capacity. Separate volume-delay functions (VDFs) may be used for truck-only lanes or for lanes with mixed auto and truck traffic to account for the impact of trucks on congestion.

- **Truck Prohibitions—**Some freeways and major principal arterials in the region may prohibit certain classes of trucks. Freight trucks and/or trucks by truck type, assigned as separate vehicle classes, can be prohibited from using these roads during traffic assignment.

These parameters are typically specific to individual assignment applications, and are not transferable between other trip-based freight applications. These parameters are often available for all trucks, and do not distinguish between freight and non-freight trucks.

The performance and usage for links on the highway network is largely determined by the assignment of automobile and non-freight trucks. The assignment processes are typically equilibrium assignment models and considered to be static. Newer assignment methods, such as dynamic traffic assignment (DTA), consider differences in departure times and capacity at various locations and times throughout the trip. However, DTA methods are incompatible with trip-based processes because they require detailed rosters of departure times and do not present a realistic option for most of the freight modeling applications.

NON-FREIGHT TRUCKS

A general structure of trip-based forecasting for non-freight trucks is shown in figure 33. It follows the traditional steps of trip generation and trip distribution to determine the total number of non-freight trucks and a corresponding trip table prior to assigning these non-freight truck trips to the highway network.

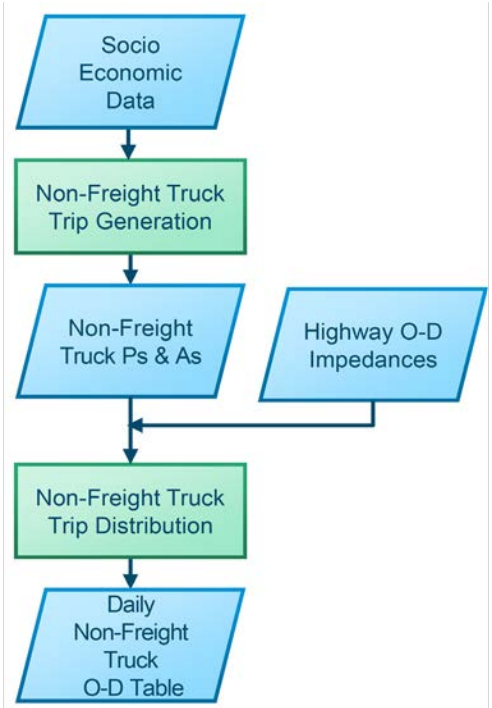

Figure 33. Flowchart. Trip-based non-freight truck forecasting method example.
(Source: Federal Highway Administration.)

Non-Freight Truck Generation

As with freight trips, trip generation rates for non-freight trucks are linked to different explanatory variables to estimate the number of non-freight trips. While the discussion for freight trips addressed all modes, this discussion applies only to trucks that do not carry freight, often referred to as service trips. Non-freight services include utilities, service business, and personal services. Delivery of goods to residences by parcel delivery are also typically included in service trips.

Chapter 5 discusses sources of all truck traffic, including O-D tables of trucks available directly, or tables that analysts can develop from location and timestamp data from vendors such as ATRI, StreetLight Data, and INRIX. The inferred O-D tables from these sources are for all trucks, both freight and non-freight trucks. To use these data to estimate non-freight truck flows, analysts should remove freight trucks from these totals. Inferred total truck O-D tables may distinguish trucks by size/body type (e.g., single unit trucks and combination unit trucks).

The zones in the total truck O-D data are typically more disaggregated than the zones used in freight estimation. Analysts can reformat the total truck database to use the same geographic zones as the freight estimation data. If analysts use reported data as the freight estimation database, they can use the mode to determine only the truck records. While truck size is not specifically stated, it may be inferred by inspection of the payload factors and the truck equipment types listed, since it is reasonable to assume that these freight trucks are all combination unit/heavy trucks.

Converting annual tons to daily tons then converting tons to trucks restates the annual tonnages as average weekday trucks. Both the total truck and freight truck O-D tables should use the same geographies and size/body type. Analysts can synthesize an estimation database for non-freight trucks by subtracting the freight truck O-D table from the total truck table.

For non-freight trucks, the production rates are equal to the attraction rates. Productions and attractions can be the dependent variable in a linear regression where the socioeconomic data (SED) can be tested as explanatory variables. Freight generation rates are dependent on the local economy, but non-freight truck trip generation rates may be transferable among regions. Table 35 shows non-freight truck rates from several trip-based applications that forecast non-freight trucks. For the Mississippi Statewide model, only a heavy truck table was provided and the rates for smaller truck types were computed based on the proportional changes to the heavy truck rates in the previous edition of *Quick Response Freight Manual* (QRFM). For the Wisconsin and Virginia Statewide models, all truck sizes were provided in the estimation dataset.

Linear regressions that use one explanatory variable are straight-forward as long as there is a direct relationship between dependent and explanatory variables. When developing a linear regression model with two variables, such as employment and households, it is possible to compute negative coefficients or arrive at counterintuitive freight production rates for some combinations of values. In these cases, analysts may explore the use of other explanatory variables or combine variables such as calculating the sum of employment and households to produce more reasonable results. Estimation data are typically available for all trucks, not just non-freight trucks. Analysts can develop non-freight truck estimation data from the total truck database only if freight truck estimation data are also available as a separate market.

Although these rates are based on recent estimation data and may include some e-commerce truck trips, the estimation data do not specifically identify e-commerce truck trips. Additionally, e-commerce truck trips may substitute for passenger retail trips, which may affect the performance of all trucks. The QRFM acknowledges that e-commerce is a dynamic and complex issue that should be better understood, but data are not available to provide transferable parameters for e-commerce.

Table 35. Non-freight truck trip generation rates per weekday.

Explanatory Variable(s)		**1996 QRFM**	**Mississippi**	**Wisconsin**	**Virginia**
Light trucks (2 axles and 4 tires; pickups, vans and SUVs)	Agriculture, Mining and Construction	1.11	N/A	N/A	N/A
	Manufacturing, Transportation, Communications, Utilities and Wholesale Trade	0.938	N/A	N/A	N/A
	Retail Trade	0.888	N/A	N/A	N/A
	Office and Services	0.437	N/A	N/A	N/A
	Total Employment	N/A	N/A	N/A	N/A
	Households	0.251	N/A	N/A	N/A
	Employment **PLUS** Households	N/A	N/A	0.023	N/A

Table 35. Non-freight truck trip generation rates per weekday (continuation).

Explanatory Variable(s)		1996 QRFM	Mississippi	Wisconsin	Virginia
Medium trucks (Single Unit, SUs, with at least 6 tires)	Agriculture, Mining and Construction	0.289	0.434	N/A	N/A
	Manufacturing, Transportation, Communications, Utilities and Wholesale Trade	0.242	0.363	N/A	N/A
	Retail Trade	0.253	0.380	N/A	N/A
	Office and Services	0.068	0.102	N/A	N/A
	Total Employment	N/A	N/A	N/A	0.042
	Households	0.099	0.149	N/A	0.013
	Employment **PLUS** Households	N/A	N/A	0.03	N/A
Heavy trucks (Combination Units, CUs, with one or more trailers)	Agriculture, Mining and Construction	1.573	0.215	N/A	N/A
	Manufacturing, Transportation, Communications, Utilities and Wholesale Trade	1.284	0.065	N/A	N/A
	Retail Trade	1.206	0.024	N/A	N/A
	Office and Services	0.514	0.014	N/A	N/A
	Total Employment	N/A	N/A	N/A	N/A
	Households	0.388	0.057	N/A	N/A
	Employment **PLUS** Households	N/A	N/A	0.011	0.016

(Source: QRFM I, Mississippi, Wisconsin and Virginia Statewide Models.)

Non-Freight Truck Trip Distribution

Trip distribution is the process that connects trips between zones. The output of trip distribution is a trip table that identifies the origins and destinations of individual trips.

Figure 34 exhibits formulation of standard gravity model for trip distribution.

$$V_{ij} = \frac{O_i D_j F_{ij}}{\sum_{j=1}^{n} D_j F_{ij}}$$

Figure 34. Equation. Origin-destination trips as a function of travel impedance and trip patterns.

Where:

V_{ij} = Trips (volume) originating at analysis area *i* and destined to analysis area *j*.
O_i = Total trip originating at *i*.
D_j = Total trip destined at *j*.
F_{ij} = Friction factor for trip interchange *ij*.
i = Origin analysis area number, *i* = 1, 2, 3, … *n*.
j = Destination analysis area number, *j* = 1, 2, 3, … *n*.
n = Number of analysis areas.

Friction factors (F_{ij}) for use with the gravity model can be based on travel time or distance between analysis areas. Analysts assign non-freight truck trip tables to highway networks that include link travel times and they use those times or distances to compute the required travel impedance between TAZs. The recommended method for single trucks and combination trucks includes the following friction factors based on travel time, t_{ij}, in minutes between analysis areas in figure 35 and 36.

Single unit trucks (6+tires):

$$F_{ij} = e^{-0.1 * t_{ij}}$$

Figure 35. Equation. Friction factor for single unit trucks as a function of travel time.

Combination trucks:

$$F_{ij} = e^{-0.03 * t_{ij}}$$

Figure 36. Equation. Friction factor for combination trucks as a function of travel time.

The coefficients in these equations are the negative inverse of the average trip length for each class of trucks. Analysts can interpret the coefficients for these friction factors as the average trip lengths for each class of trucks. The approach assumes that the form of friction factors for trucks of all classes follows a smooth continuously exponential function as time increases. While these parameters are transferable, analysts can expect them to change as congestion increases and the size of the study area increases. The ratio among these parameters by truck size is more consistent, suggesting that the average trip lengths for heavy trucks are greater than the average trip lengths for medium trucks.

Average travel times can be computed from the non-freight truck estimation data and tables of highway times between zones, as shown in table 35. These average travel times can then be used in the distribution of non-freight truck trips. While the non-freight truck trip generation rates are expected to be similar among regions, the average trip lengths should be a function of the longest possible trip in the model. Longer average trip lengths are possible when the geographic area covered by the detailed model is also larger.

Table 36. Non-freight truck trip distribution parameters per weekday.

Truck Type	Distribution Parameter	QRFM 1996	Mississippi	Wisconsin	Virginia
Light trucks (2 axles and 4-tires; pickups, vans and SUVs)	Coefficient	-0.080		-0.045	
	Average Trip Length (mins)	12.5		22.0	
Medium trucks (Single Unit, SUs, with at least 6 tires)	Coefficient	-0.100	-0.070	-0.040	-0.041
	Average Trip Length (mins)	10.0	15.0	25.0	24.3
Heavy trucks (Combination Units, CUs, with one or more trailers)	Coefficient	-0.030	-0.020	-0.025	-0.026
	Average Trip Length (mins)	33.3	50.0	42.0	38.3

(Source: QRFM I, Mississippi, Wisconsin and Virginia Statewide Models.)

Assignment

Trip tables of non-freight trucks have the same issues discussed for freight trucks including truck restrictions, passenger car equivalencies, and volume delay curves (VDFs). If the analysis requires measures of usage and performance for non-freight trucks, analysts should label and track model outputs separately throughout the assignment process. Trip-based models that include non-freight trucks often use a static traffic assignment, though more sophisticated dynamic traffic assignment methods are feasible in the future using departure times at a high level of resolution.

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CHAPTER 10. FREIGHT SUPPLY CHAIN AND NON-FREIGHT TRUCK TOUR FORECASTING

The previous chapter discusses trip-based approaches for freight and non-freight forecasting. Trip-based approaches provide well established methods for analyzing freight flows, but do not account for the entire chain of truck movements from shipper to receiver.

The movements of freight goods can be linked to supply chains from a shipper to a receiver consisting of individual trips of freight goods by different modes. Non-freight truck tours may consist of many individual trips by the same truck. In supply chain forecasting, the process is distinguished by the different components that constitute each step of the supply chain. These are the most complex methods of developing freight models and the subject of this chapter.

FREIGHT SUPPLY CHAIN

Supply chain models focus on estimating commodity freight flows across modes. A supply chain may use one or more freight modes and can include:

- The initial shipment of cargo to a rail terminal.
- A rail trip from the rail terminal.
- A truck trip to deliver the cargo to its final destination.

The supply chain is determined by the utility of each modal link or trip in the supply chain and handling level of service (e.g., time and cost) at the transfer points between trips along the supply chain. These transfer points or nodes are often called transport logistics nodes (TLN).

The type of cargo transported is maintained throughout the entirety of the supply chain. The cargo unit definition may also include certain attributes of the freight cargo (e.g., shipment size and shipment frequency) that influence the choice of a specific supply chain. Freight goods are forecasted between the origin (shipper) and the destination (end receiver). The modes may change at TLNs between origin and destination, unlike trip-based models that maintain a single mode between origin and destination. The linked trips across transfer points are similar to truck touring models; multiple trips are linked with transported freight goods as the common attributes. However, the scope of the supply chain models focuses on freight trucks and does not include all truck travel.

Supply chain freight models do not consider a freight trip by a single mode, but link multiple trips by mode into a supply chain. This is similar to a tour-based passenger model, with the exception that the final destination is not a return to the supply-chain origin. The alternatives in a supply chain choice model are all the available supply chains between origin-destination (O-D) pairs. The supply chain includes all modal sequences and routes, and the application of a supply chain model allocates freight among the alternatives based on the utility of each supply chain.

Figure 37 provides a possible structure of a supply chain model beginning after Firm Synthesis.

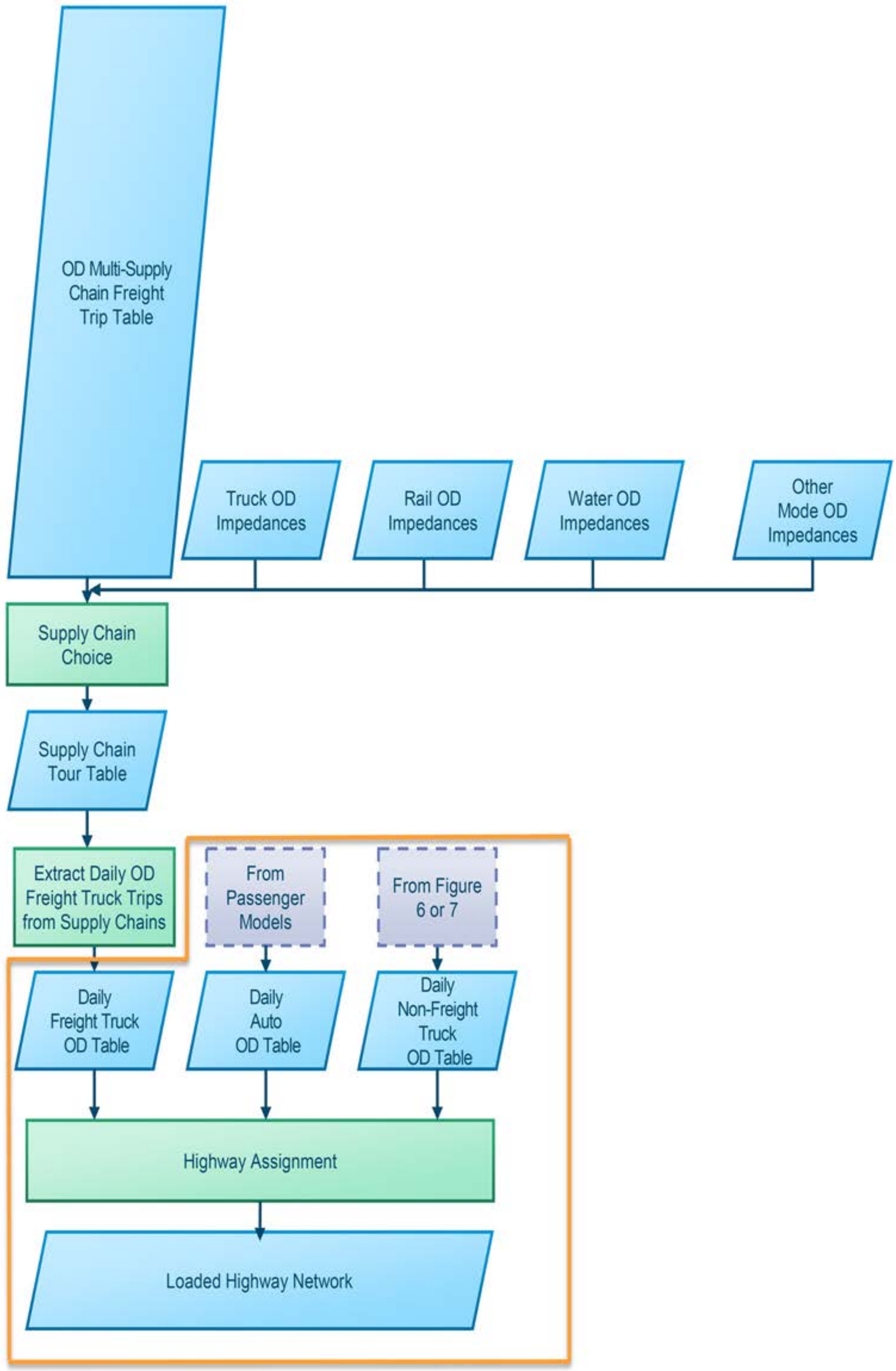

Figure 37. Flowchart. Supply chain freight models framework example.
(Source: Federal Highway Administration.)

The first key input to a supply chain model includes freight flows by O-D that are derived from the Freight Analysis Framework (FAF) by aggregating all reported supply chains by commodity. Although it is possible to develop freight O-D flow models to estimate this table using a supply chain-based commodity flow database, in the absence of a multi-supply chain trip table, a simpler table derived from FAF is used as an input.

Second, the input freight trip table is combined with information about the travel times and costs by all competing freight modes to address the choice of supply chains (figure 37). To better understand the choice of mode and the location of the various trip ends of the commodity chain, a supply chain model allocates the total commodity chain flows to specific commodity chains.

Third, different commodities follow different paths from the shipper origin to the receiver destination of the supply chain. The ability to separate the observed aggregate flows into individual supply chains provides mode and locational information, which is valuable in freight planning (figure 37). The ability to develop utility choice information for these supply chains allows the creation of composite interzonal shipping costs (utilities) that inform the freight generation and freight distribution steps of the model.

Fourth, supply chains may consist of multimodal trips that include both trucks and non-truck modes. Therefore, the truck trips need to be extracted from the supply chain prior to the network assignment step. The conversion from supply chain tours to truck trips uses the transfer points along the supply chain as the origin and/or destination of individual truck trips.

Firm Synthesis

In supply chain freight models, the first step is firm synthesis—the process of creating individual firm objects to represent establishments and replicate their freight movement and travel behavior. This process uses employment data for the modeling region, which may be available in different forms, to assemble a record of establishments with location, size, industry, production, and consumption information. For a fully disaggregate approach, the ideal form of data would be an employment database with records for individual establishments. These records would include addresses for physical locations, number of employees, and detailed NAICS industry and commodity codes. Employment databases with this level of detail are produced by commercial vendors, such as InfoGroup, and can be acquired for a fee; however, they may not be comprehensive in their coverage of all industry sectors, such as agriculture, construction, public administration, and self-employed individuals and small businesses.

Publicly available datasets include the Longitudinal Employer-Household Dynamics (LEHD) and County Business Patterns (CBP) datasets, both published by the U.S. Census Bureau. These datasets are discussed in the next section.

The process by which these more-aggregate datasets are transformed into synthetic firms for simulation modeling is relatively straightforward, and depends on the level of aggregation in the data and the desired level of disaggregation for the model. The basic steps are as follows:

1. **Develop joint distributions of the number of establishments by NAICS codes and employee-size groupings.** Start with the most disaggregate groupings of NAICS (e.g., six digits for CBP) and establishment size available in the source data, and aggregate as necessary to the groupings needed for the model. (Aggregation at the county level is typical for LEHD or CBP.)

2. **Enumerate establishments.** Create an establishment record/object for the simulation (enumeration) for each count of an establishment by establishment size and category. This should provide both a NAICS code attribute and an establishment-size attribute. If locational attributes are needed for a finer geographic resolution than the county, then distribute the synthesized establishments to traffic analysis zone or similar geography using local employment data. If commercial employment data are available, then use these data to create synthetic establishments in more-precise geographic locations.

3. **Add production.** The Make Tables (commodities that are produced by each industry) from an Input-Output (IO) account are used to estimate the dollar value of commodities produced by synthetic establishments, differentiated by industry and establishment size. For some industries that produce multiple commodities, one approach is to select a single production commodity. This permits estimation that the amount produced is proportional to the establishment size. This can then be done for all establishments in the United States that produce that commodity domestically, which can also be derived from the Make Table. Generally, selecting more than one commodity will significantly increase the computational and memory requirements.

4. **Add consumption.** The Input/Output Use or Direct Requirements table can generate consumption commodities using a production commodity and quantity. The Direct Requirements table shows the dollar amount of each input commodity needed to produce a dollar of the output (production) commodity. Because most production commodities use scores of input commodities, simplifying assumptions may be necessary to limit the number of modeled input commodities to a manageable number (and possibly rescaling total quantities to ensure adequate representation of flows).

Following these steps produces a list of establishments with location, establishment size, industry, production, and consumption details that aggregate to meet the joint distributions of establishments by industry and establishment size.

Trip Table

Freight trip tables can be created by unlinking individual tours that are an output of a tour model. A stop on a supply chain tour is considered a trip origin, and the next stop on the supply chain is considered a trip destination. The variables considered in the supply chain choice include shipment size and frequency, which are unique to each shipper-receiver agent and cannot be easily aggregated.

Commodity flow databases, such as the FAF, are aggregate flows over all commodity chains. To better understand the choice of mode and the location of the various trip ends for the legs of the commodity chain, a supply chain model allocates the total commodity chain flows to specific commodity chains. The example below will help explain the "links" of various commodity chains in consumer goods transportation.

In this example, the description of three paths for different commodities underscores that the aggregate FAF commodity flows consist of many different paths with distinct legs. Presenting the path options for transporting different types of consumer goods also highlights two key elements of the supply chain approach:

1. At each decision point along the path, a model considers all of the available links at each location, then uses these choices to construct the legs of the path.
2. A set of all feasible paths is an input to a decision choice model that considers the composite utilities along each feasible path to allocate aggregate freight flows among the paths.

Finally, the consumer goods example illustrates that, while FAF reports aggregate commodity flows between large regions, the actual choice of the supply chain requires the identification and quantification of the attributes of the shipper and receiver agents, including the size and frequency of the freight commodity being transported.

Consumer Goods Example

This supply chain example demonstrates the movement of consumer goods from an overseas goods manufacturer through warehousing and distribution centers to metropolitan area retailers. This supply chain is typical of those operated by "big box" retailers in the wholesale/retail sector. For this example, the FAF zone structure is used to distinguish between three zones:

1. The supply chain origin is the overseas zone.
2. The Port of Entry Zone is in the U.S.
3. The supply chain destination zone is the Chicago portion of the Chicago Combined Statistical Area (CSA).

The commodities moved through this supply chain cover the full gamut of consumer merchandise and retail goods, including clothing, household goods, building hardware, and electronics; thus, this discussion may be applicable for several commodities. These commodities are usually transported in sealed intermodal containers. There has been enormous growth in the use of intermodal containers in both international and domestic trade over the past 50 years. This growth has led to standardization in container sizes and conveyance equipment, enabling carriers to realize tremendous efficiencies in the loading and unloading of ships, rail cars, and trucks. Standardization has also given shippers greater flexibility in designing their supply chains, enabling them to move containers by truck and rail, by truck and ship, or by truck, ship, and rail.

The standard international container in service today is either a 20-foot long container (a twenty-foot equivalent unit (TEU)) or a 40-foot long container (a forty-foot equivalent unit (FEU) equal two TEUs). Most waterborne international trade consumer goods are transported in FEU containers.

Figure 38 shows the typical supply chain for the movement of consumer goods in shipping containers. The supply chain involves the following freight movements:

- Travel from an overseas factory to an overseas port by truck or rail is shown as a black line.
- Travel from an overseas port to a U.S. port by containership is shown as a blue line.
- Travel from a U.S. port to a local intermodal rail terminal by truck is shown as a black line.
- Travel from a local intermodal rail terminal to a distant U.S. rail intermodal terminal by train is shown as a green line followed by truck travel to a warehouse or distribution center, shown as a black line.
- Truck travel from the distribution center to a Chicago retail store is shown as a black line.

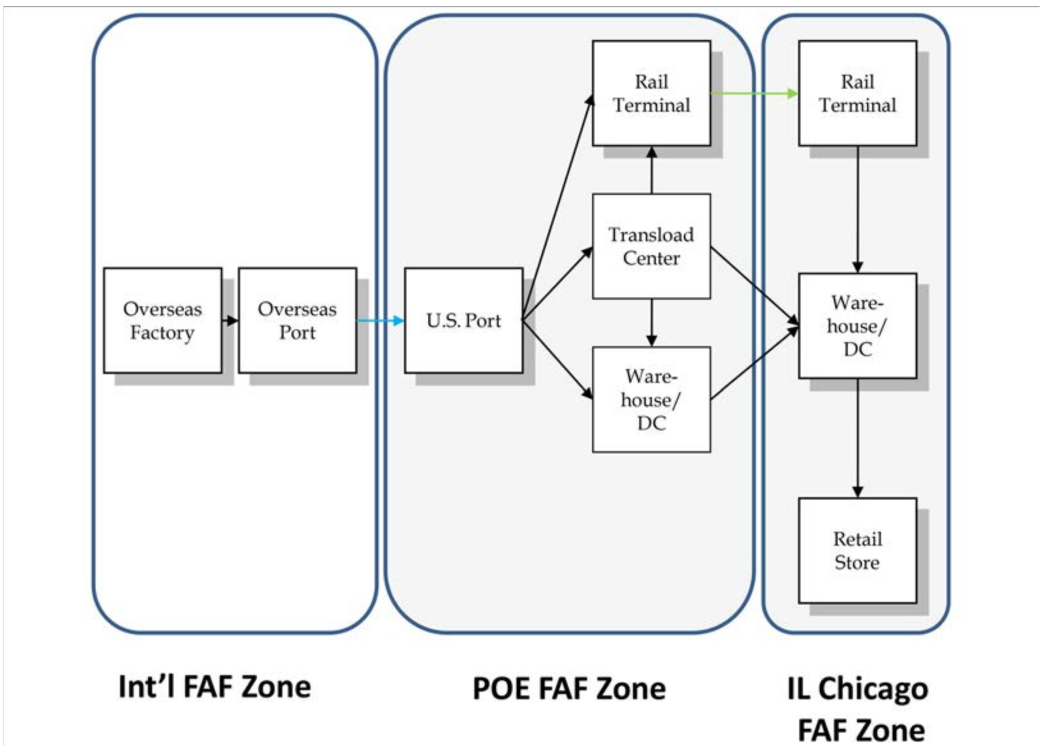

Figure 38. Flowchart. Supply chain for consumer goods transportation example.
(Source: Federal Highway Administration.)

The three zones that are shown are intended to represent the international zone, the port of entry (POE) zone, and the domestic destination zone.

There are multiple alternatives for moving consumer goods between U.S. ports and Chicago retail stores. The major paths are described individually as they involve different facilities and modes of transportation, which affects the types of data available to freight planners.

First, the FAF includes flows for all three zones. FAF paths that include multiple domestic modes are designated as a multiple mode (e.g., truck-rail-truck), which distinguishes them from paths that use only a single mode (e.g., truck). The flow information applies to the entire path and is not separable by leg of the supply-chain.

Consumer Goods Path 1 via Intermodal Rail: The dominant path in the consumer goods supply chain is from overseas factory to U.S. retailer via containership and intermodal rail—the topmost highlighted path shown in figure 39. Within the U.S., the transportation links are as follows:

- **U.S. port to local intermodal rail terminal.** Containerized goods are transported from the U.S. port to an intermodal rail terminal via truck/intermodal chassis.

- **Local intermodal rail terminal to destination intermodal rail terminal.** Containerized imported goods are transported from local intermodal rail terminal to geographically distant intermodal rail terminals via rail.

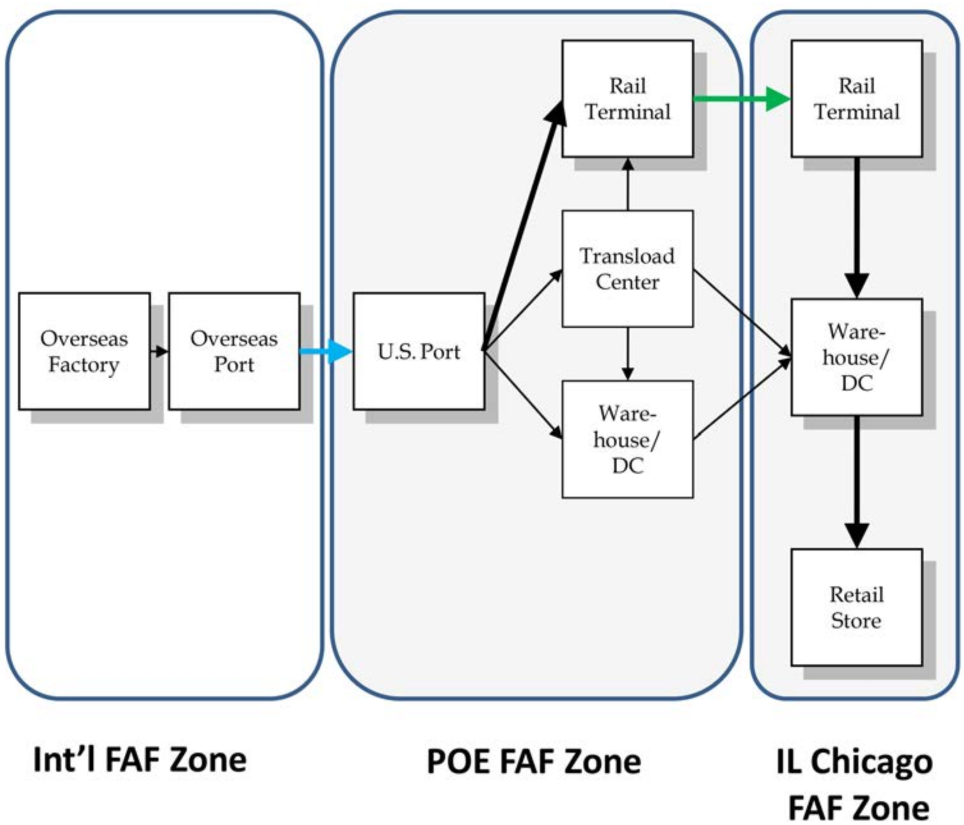

Figure 39. Flowchart. Path 1 supply chain for consumer goods transportation example. (Source: Federal Highway Administration.)

- **Destination intermodal rail terminal to distribution center.** Containerized goods are transported from the destination intermodal rail terminal to local warehouses and distribution centers via trucks/intermodal chassis.

- **Distribution center to retail store.** Pallets, boxes, or racks of consumer products are transported from warehouses and distribution centers to final retail outlets via truck. Depending on the size of the retail store, carriers may use straight trucks or tractors and semi-trailers from 28-foot to 53-foot long.

The key features and sources of data for these links are summarized in table 37.

Table 37. Exporter to retailer supply chain via containership and intermodal rail.

	Overseas Factory to Overseas Port	Overseas Port to U.S. Port	U.S. Port to Local Rail Terminal	Local Rail Terminal to Destination Rail Terminal	Destination Rail Terminal to DC	DC to Retail Store
Commodity	Consumer goods	Consumer goods	Consumer goods	Consumer goods	Consumer goods	Consumer goods
Packaging	Container (international)	Container (international)	Container (international)	Container (international)	Container (international)	Pallets, boxes, racks, etc.
Mode	Truck (container on IMX chassis)	Container-ship	Truck (container on IMX chassis)	Rail (IMX railcar)	Truck (container on IMX chassis)	Truck (53', 48', and 28' trailers; straight trucks)
Data available in FAF	No	Yes, International Trade Flows	No	Yes	No	No

Consumer Goods Path 2 via Transload Center: For retailers that import large volumes of goods, they can use an alternative path to truck containers to a warehouse/transload facility, where the contents of the containers can be unpacked, sorted, and then repacked for onward shipment in larger domestic containers or truck trailers. Transloading is done because the contents of seven 40-foot international containers can often be repacked into five 53-foot domestic containers or truck trailers, resulting in five truckload trips, instead of seven truckload trips.

This approach is cost effective if the transportation savings are greater than the cost of unpacking and repacking the goods. Over the years, the relative cost differential has varied considerably depending on the volume of transloading. Transloading also makes it possible for shippers to assemble goods from several single-commodity international containers into a domestic container or truck trailer of mixed goods for direct delivery to a specific retail store.

Transloading also accommodates the "postponement" of a shipment. Inbound shipments, which may have been ordered several months earlier, are held at the transload center and shipped to distribution centers and retail stores "on demand." This allows companies to avoid stock-outs of fast-selling items in one area, and over-stocking of slow-selling items in other areas.

This highlighted path is shown in figure 40. Within the U.S., the transportation links are as follows:

- **U.S. port to transload facility.** Containerized imported goods are transported from U.S. ports to nearby transload facilities via truck/intermodal chassis. The transload facilities are typically small- to medium-sized warehouses or truck terminals set up to handle cross dock operations. At the transload facility, the international containers are emptied and the contents repacked in domestic containers or truck trailers.

- Transload facility to local rail terminal. Goods repacked into domestic containers are then trucked from the transload facility to the local rail terminal.

- **Local intermodal rail terminal to destination intermodal rail terminal.** Containerized imported goods are transported from local intermodal rail terminal to geographically distant intermodal rail terminals via rail.

- **Destination intermodal rail terminal to distribution center.** Containerized goods are transported from the destination intermodal rail terminal to local warehouses and distribution centers via truck/intermodal chassis.

- **Distribution center to retail store.** Pallets, boxes, or racks of consumer products are transported from warehouses and distribution centers to final retail outlets via truck. Depending on the size of the retail store, carriers may use straight trucks or tractors and semi-trailers from 28 to 53 feet long.

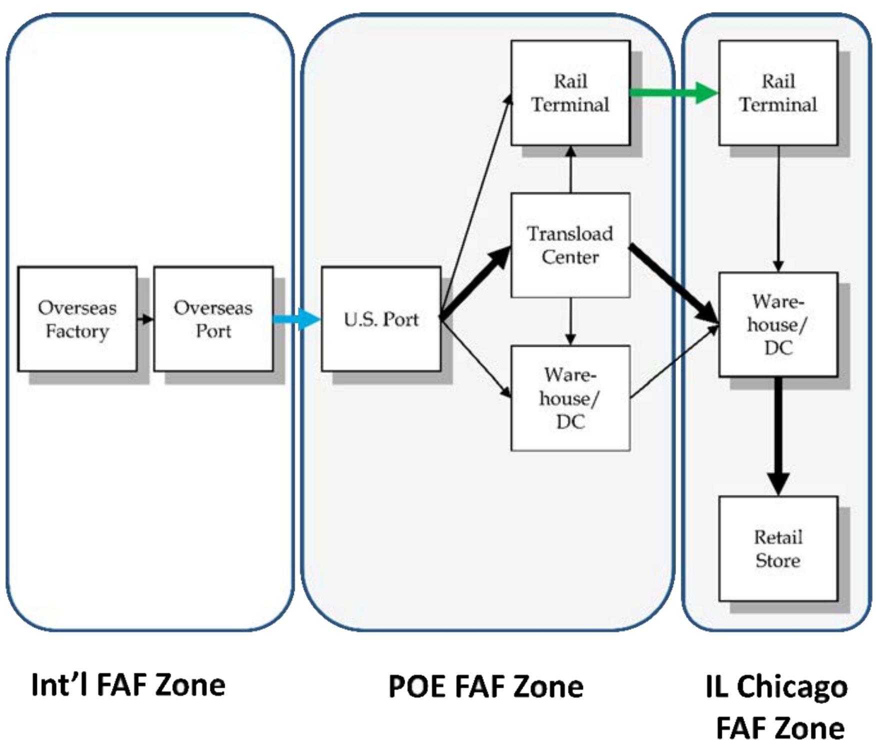

Figure 40. Flowchart. Path 2 supply chain for consumer goods transportation example. (Source: Federal Highway Administration.)

The key features and sources of data for these links are summarized in table 38.

Table 38. Supply chain via a transload facility.

U.S. Port to Transload Facility		**Transload Facility to Local Rail Terminal**	**Transload Facility to DC**
Commodity	Consumer goods	Consumer goods	Consumer goods
Packaging	Container (international)	Pallets, boxes, racks, etc. in container (domestic) or truck trailer	Pallets, boxes, racks, etc. in truck trailer
Mode	Truck (container on IMX chassis)	Truck (container on IMX chassis)or trailer	Truck (53’, 48’, and 28’ trailers; straight trucks)
Data available in FAF	No	No	No

Consumer Goods Path 3 via Warehouse or Distribution Center: Transloading is a cost- effective option if the shipper or receiver is handling large volumes of goods. Shippers who handle moderate volumes of goods or handle high-value goods often prefer to move their goods from the port to a local warehouse or distribution center, and then forward some or all of the goods by truck.

This highlighted path is shown in figure 41. Within the U.S., the transportation links are as follows:

- **U.S. port to local warehouse or distribution center.** Containerized imported goods are transported from U.S. ports to nearby warehouses or distribution centers via truck/ intermodal chassis.

- **Local distribution center to destination DC.** Pallets, boxes, or racks of consumer products are transported from warehouses and distribution centers to final retail outlets via truck. Depending on the size of the retail store, carriers may use straight trucks or tractors and semi-trailers from 28 to 53 feet long.

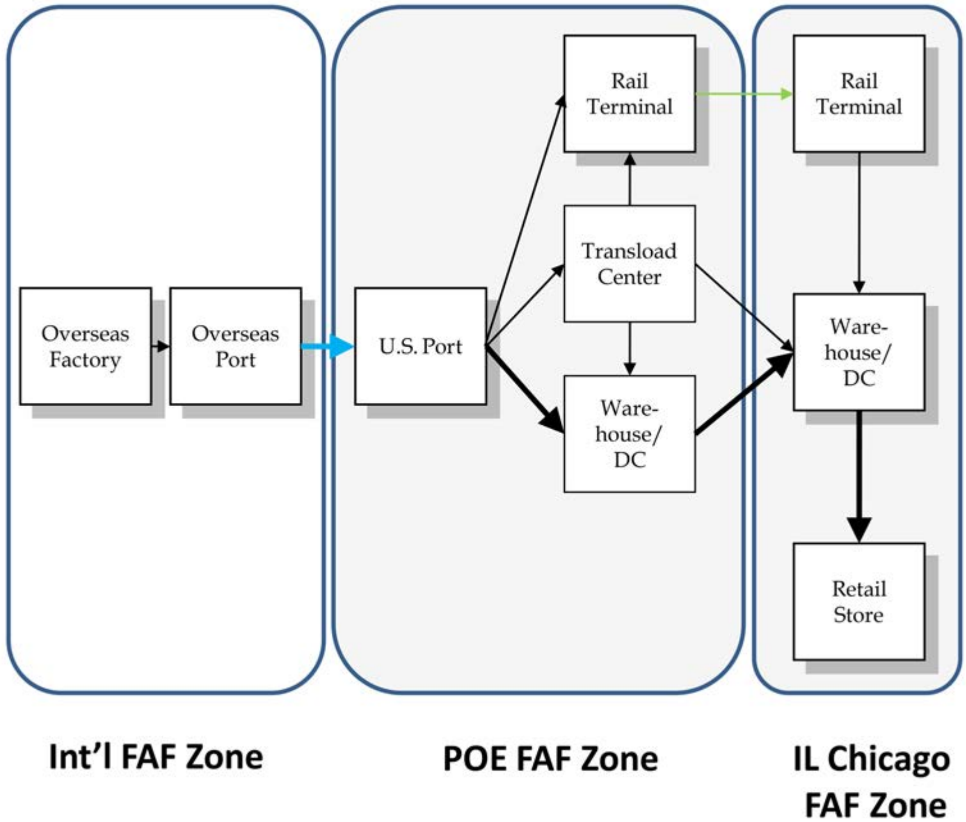

Figure 41. Flowchart. Path 3 supply chain for consumer goods transportation.
(Source: Federal Highway Administration.)

The key features and sources of data for these links are summarized in table 39.

Table 39. Supply chain via a local warehouse or distribution center.

	U.S. Port to Local Warehouse or DC	Local Distribution Center to Destination DC
Commodity	Consumer goods	Consumer goods
Packaging	Container (international)	Pallets, boxes, racks, etc. in truck trailer
Mode	Truck (container on IMX chassis)	Truck (53', 48' 28' trailers; straight trucks)
Data available in FAF	No	No

Supply Chain of Paths

The listing of different potential paths by commodity demonstrates that the aggregate FAF commodity flows consist of many different paths with distinct legs. The ability to separate these flows into individual chains provides mode and locational information that is valuable for freight planning purposes. Additionally, the ability to develop utility choice information for these chains allows the creation of composite interzonal shipping costs, which informs the freight generation and distribution steps of the macro-scale model.

While figure 39 and figure 40 show generic rail terminals, distribution centers, and retail stores, these are replaced by specific locations within the zone structure of the supply chain model. Key elements of the approach include the following:

- At each decision point in the path, a decision model (e.g., a logit choice model) considers all available next links at each location and uses these choices to construct the legs of the path.
- A set of all feasible paths is constructed and a decision choice model evaluates the composite utilities along each feasible path to allocate aggregate flows among different path options.

Although FAF reports aggregate commodity flows between large regions, the evaluation and choice among supply chains is sensitive to the characteristics of the freight commodity being transported, including attributes related to shipment size and frequency.

The trip-based freight methods discussed in chapter 9 can be used to create aggregate freight tables. The common practice is to develop the input table through disaggregation of the FAF by identifying the geographic location, industry, and size of possible suppliers.

The commodities produced by individual shippers are then identified. These are paired with the receivers of the commodity, using a “Use” table from an economic model and the distance between the shipper and the receiver.

The size and frequency of the commodity transported are derived from the respective sizes of the shipper and receiver. This information is used to disaggregate the FAF to a more detailed table of commodity flows between shipper-receiver agents. These agents choose among supply chains based on the attributes of those supply chains, including the handing times and costs at various transport logistic nodes (TLNs) that connect the trips and comprise the supply chain.

The supply chain choice forecast can be evaluated by the transportation agency. The total freight flows between the agents by all available supply chains is obtained by disaggregating the FAF forecast. If the economy changes and new shippers or receivers are formed or the volume of freight transported between those shippers and receivers differs from the FAF assumptions, this is not reflected in the supply chain forecast. Other details include:

- The tours reported by the supply chain are modal trips between the stops on the supply chain, which reflect TLNs.
- The trips between stops on the supply chain can be unlinked to a traditional table of O-D flows for use in network assignment.
- The modes used on each leg are identified, and that information can be used to separate the freight flows into modal O-D tables.

Assignment

The trip tables by commodity and by mode reflect the flow of goods that are used in assignment. Static assignment is used since supply chains lack information, such as the time of departure and time of arrival.

The modal freight trip tables are stated in multimodal tons, which allows them to be allocated among supply chains. While these flow units can be assigned to modal networks for informational purposes, performance-based rules in modal networks are typically vehicle based. To forecast assignments where the paths are chosen by the performance of the network, it is necessary to convert to the flow unit used in modal path assignments. Tours unlinked to modal O-D trips need to be converted from annual tons to daily trucks using a payload factor approach similar to the one used for trip-based tonnages. For a shared use network, such as freight trucks on highways, the proper choice of paths requires the availability of all trip tables that contribute to path performance.

Performance

Performance is based on the reported link performance, including the origin-destination path skim times that are based on link times. Unless the assignment considers congestion, there may be no reason to compute performance.

NON-FREIGHT TRUCKS

Tour-Based Truck Models

Tour-based non-freight truck models produce an O-D trip table using a tour demand structure to leverage the tour constraints, and to improve stop location and time-of-day estimates. The unit of a tour is a truck, and there is no mode choice component similar to non-freight truck trip tables. When converting tours to the trip table for assignment, intermediate stops are treated as origins and destinations.

While truck tour models have been developed, their estimation databases do not typically differentiate between freight and non-freight trucks. While a truck tour model may be based on a commercial vehicle survey that identifies travel purpose, there is no assurance that the definition of freight in the survey is the same definition of freight used in the FAF to estimate the supply chain freight trips. Without an estimation dataset for non-freight trucks, the components of the truck tour model should not be assumed to represent non-freight trucks. The estimation data used to develop a truck tour model may already include the truck trips from the supply chain model.

Truck tour models produce trip lists for all the freight delivery trucks and commercial vehicles in the region that can be assigned to a transportation network. The truck touring model components predict the elements of the pick-up and delivery system within the region through several modeling components:

1. **Vehicle and tour pattern choice.** Predicts the joint choice of whether a shipment is delivered on a direct or a multistop tour and the size of the vehicle that makes the delivery.

2. **Number of tours and stops.** Predicts the number of multistop tours required to complete all deliveries and estimates the number of shipments the same truck delivers.

3. **Stop sequence and duration.** Sequences the stops in a reasonably efficient sequence but not necessarily the shortest path. Predicts the amount of time taken at each stop based on the size and commodity of the shipment.

4. **Delivery time of day.** Predicts the departure time of the truck at the beginning of the tour and for each subsequent trip on the tour.

The output from the truck touring model can be integrated with a regional passenger travel model for highway assignment and then becomes part of the travel demand modeling system.

Trip Tables

Thus far in practice, tour-based truck models have been created for all trucks, but infrequently for non-freight trucks. The model components for non-freight trucks are expected to follow the steps shown in figure 43. However, the trucks in supply chains that carry freight and the stops that serve freight should be excluded from those models if they are to be combined with the trip tables output from supply chain models.

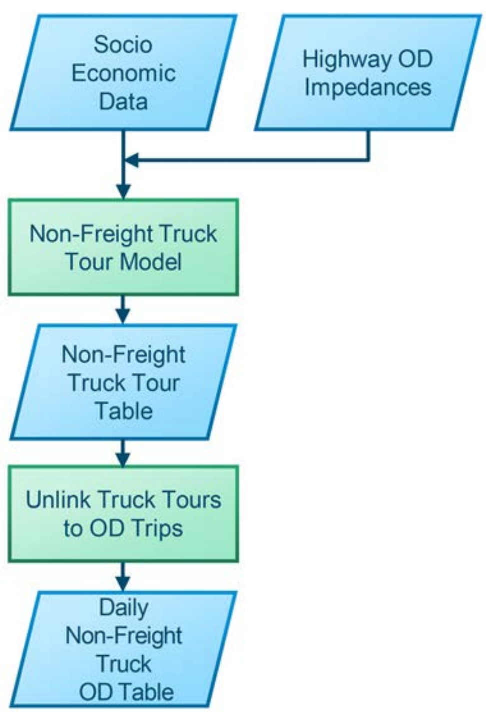

Figure 42. Flowchart. Tour-based truck model framework example.
(Source: Federal Highway Administration.)

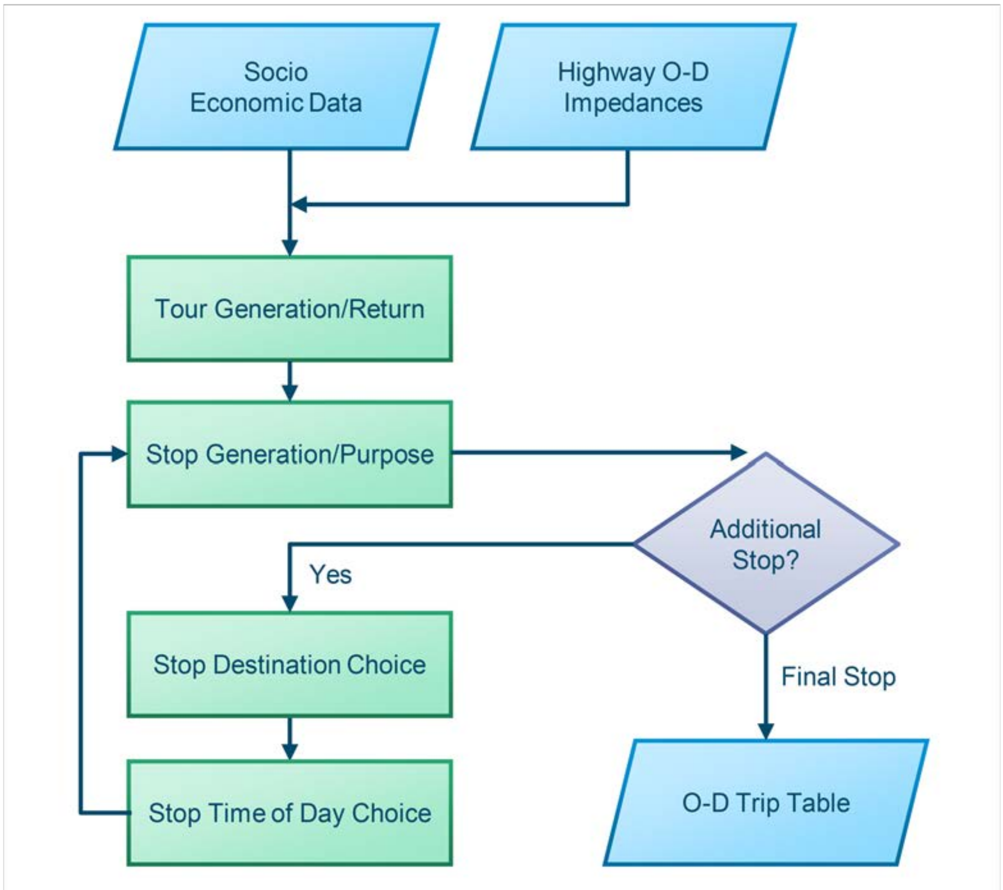

Figure 43. Flowchart. Truck tour model framework example.
(Source: Federal Highway Administration.)

Assignment

As shown in figure 43, truck tour models include a stop time-of-day choice component and forecast the arrival times, stay durations at stops, and departure times from stops. These times support the detailed trip tables that are required for dynamic traffic assignment (DTA). However, in most cases, the non-freight trucks are assigned along with the freight trucks from supply chain models that do not support this level of temporal detail. As a result, the static traffic assignment (STA) used for freight trucks is used for the highway network assignment of all vehicle trip tables.

Performance

The link performance forecast for non-freight trucks is the same as the link performance of freight trucks that are part of supply chains. The path performance may also be the same if the non-freight trucks follow the same assignment rules. If freight trucks are preloaded on the highway network or otherwise experience different assignment rules, non-freight trucks may use different paths and have different performance measures from freight trucks along origin-destination markets.

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CHAPTER 11. MODEL DEVELOPMENT ISSUES

This chapter discusses issues that may arise during the model development process described in chapters 6 through 10. This chapter focuses on potential issues related to:

- Inputs provided by other models, such as economic or land use models.
- Outputs to air quality conformity and project prioritization analyses.
- Validation of freight models focusing on the separate steps of trip generation, trip distribution, modal split, and network assignment.

The methods described in chapters 6 through 10 provide a roadmap for developing different components of a freight forecasting model. The discussion and examples provided in these chapters are illustrative and not prescriptive. One or more of the methods discussed can be combined within a single freight forecasting application. For example, the forecasting of freight goods may use a trip-based method that is combined with a tour-based method that examines non-freight truck travel patterns.

Methods may also vary by geography; a characteristic case is the use of different methods for freight trips that have an external trip end. A model may use a National network when forecasting freight trips and external stations for the non-freight trips. The methods do not need to be confined to a single application. The output from one application method may be used as an input to another application method. For example, an application may forecast trip tables by mode and not have a method to assign trips, while another method could assign those trip tables. By combining different applications, analysts can develop more accurate forecasts.

INPUTS FROM OTHER MODELS

The methods described in previous chapters require inputs that come from other models and sources. For example, socioeconomic data may be developed from land use or economic models. These other models typically require inputs that are themselves outputs of the freight forecasting process. For example, the travel time between geographies after accounting for congestion is an output of travel demand forecasting models.

To ensure consistency between the inputs and the outputs of a freight forecasting model, it is common to operate the models iteratively until stability between the model inputs and outputs is achieved. If analysts operate these models iteratively, they must ensure consistency in the inputs and outputs of all model components in both models. For example, the cost of transporting freight that is used to forecast the overall economic demand should be consistent with the actual cost that can be computed after that freight is assigned to modal networks.

OUTPUTS TO OTHER MODELS

The outputs from freight forecasting models, such as trip tables, network assignments, and performance measures, are often used in other forecasting models. For example, the emissions forecast in air quality conformity models depends on the volume and performance of freight vehicles. A project prioritization model may quantify the benefits in terms of time savings, including those that accrue to freight vehicles, compared to the cost of implementing those same projects.

Models that use the outputs from freight forecasts can also benefit from iterative operations. The network and assumptions used to develop freight forecasts should be consistent with the networks and project commitments assumed in other models or result from post-processing analyses. If they are not, an iterative process should be used until consistency is achieved. Freight forecasts that depend on network improvements that cannot be implemented cannot produce meaningful freight forecasts or identify the proper implications of those freight forecasts.

MODEL VALIDATION

Model validation involves testing a model's capability to predict current travel demand to determine if the model can effectively predict future travel demand. Model validation issues are not unique to freight models; the Federal Highway Administration's (FHWA) Travel Model Validation and Reasonableness Checking Manual discusses this at length and can be accessed at: https://www.fhwa.dot.gov/planning/tmip/publications/other_reports/validation_and_reasonableness_2010/fhwahep10042.pdf.

Freight travel models must replicate observed conditions within reasonable ranges before they can be used to produce reliable forecasts. As practitioners continue to refine and improve travel demand forecasting processes, the forecast's credibility depends largely on proper validation. As travel demand models have become more complex, the validation procedures become more complex as well. There are tradeoffs between increasing the confidence in a model's accuracy and the corresponding cost of data collection and the effort to validate models.

It should also be noted that a balanced approach to validation is needed not to compromise the policy sensitivity of the model by overemphasizing the need to validate the model to match closely the observed freight flows. Validation tests used to evaluate models range from simple reasonableness assessments of model outputs to sophisticated statistical techniques.

Model validation and reasonableness tests involve a two-part procedure—calibration and validation. Model calibration is the process of adjusting input parameter values to match observed travel demand patterns, and model validation is the process of comparing the model predictions to observed values.

Model validation data should be obtained from different sources than those used in estimating the model. In *Quick Response Freight Methods* (QRFM), validation data refers to those data sources that practitioners can use to compare with model predictions to determine the reasonableness of the model results. Model validation often includes adjustments, referred to as calibration, to the model parameters to improve the match between observation data and model estimates.

Although the same overall validation principles apply to freight models as in passenger models, there are some important differences in freight model validation due to the nature of freight data and include the following:

1. External validation of commodity flows is not possible without corresponding data.
2. Truck traffic counts don't distinguish between freight and non-freight trucks requiring the validation to reflect both types of trucks.
3. Non-truck freight modes do have good sources of external validity, such as the Waybill and Waterborne sources described in chapter 3.

Trip Generation Validation

Trip generation estimates the freight goods or truck trips to and from each traffic analysis zone (TAZ) in the study area. Socioeconomic data are used to estimate the trips that take place within the study area, referred to as internal-internal; and the trips that are partially within the area, referred to as external-internal or internal-external. Like passenger forecast models, the freight trip generation model estimates trip productions and trip attractions.

A major drawback with the linear regression models is that the explanatory variables are often interrelated and correlated. Linear regression models also assume that the relationship between the explanatory variables, typically employment for freight and truck models, and the generated truck trips is linear.

Trip generation validation should compare the estimated trips against observed data. This comparison should vary by market sector and geography, as freight travel characteristics differ across these dimensions. The spatial distribution of land use and employment drives the variability of truck travel behavior by geography. The nature of freight flows and the commodity being shipped influences the travel behavior of trucks across different weight classes.

The differences between observed and estimated trip totals may be caused by estimation errors in the trip generation model, sampling errors in the truck travel survey, measurement errors in the field, or a combination of these factors. Trip generation differences are reduced to acceptable ranges during the model calibration process to achieve validation. Calibration procedures may include adjusting trip rates, re-estimating models, regrouping sectors, revisiting inputs and measures of observed trips generated, and reclassifying truck types.

Trip Distribution Validation

Trip distribution connects trip productions with trip attractions to create flows of travel, called trip tables. Critical outputs of trip distribution are trip length travel orientation, such as suburb to central business district (CBD) or CBD to suburb, and the resulting magnitude of traffic volumes. The gravity model is the most common model used for trip distribution; inputs for gravity trip distribution models are trip productions and attractions for each zone, a measure of travel impedance between zones, and a friction factor to quantify the impact of the impedance based on the type of trip. The trip productions and attractions are derived from the trip generation model, while the travel impedances are obtained from determining the path of least resistance between each pair of zones.

During calibration of trip distribution models, the observed and estimated trip lengths are calculated using network-based impedances. Most travel demand modeling packages automatically calculate average trip length for all origin-destination trip interchanges. This measure is the average travel time from the skims matrix weighted by the trip matrix. Truck travel surveys ask truckers to report travel times; however, analysts consider these times unreliable compared to the origin and destination information obtained from the survey. The reported travel times are used only to provide an approximate estimate of truck trip lengths in the model validation.

One source of data that can be used for deriving trip length distributions that are used in model validation is the CFS PUMS dataset that can be accessed at https://www.census.gov/data/datasets/2012/econ/cfs/2012-pums-files.html. A plot of the trip length frequency distribution is provided by figure 44, which shows how well the estimated trip distribution model replicates observed trip lengths over the range of travel times. The coincidence ratio is used to compare these two distributions. Generally, the coincidence ratio measures the percentage of the area that “coincides” for the two curves, and measures the percentage of the total area that is common to both distributions. In this case, the freight model trip length distribution reflects the corresponding observed TRANSEARCH data with a coincidence ratio of 82 percent between the two distributions.

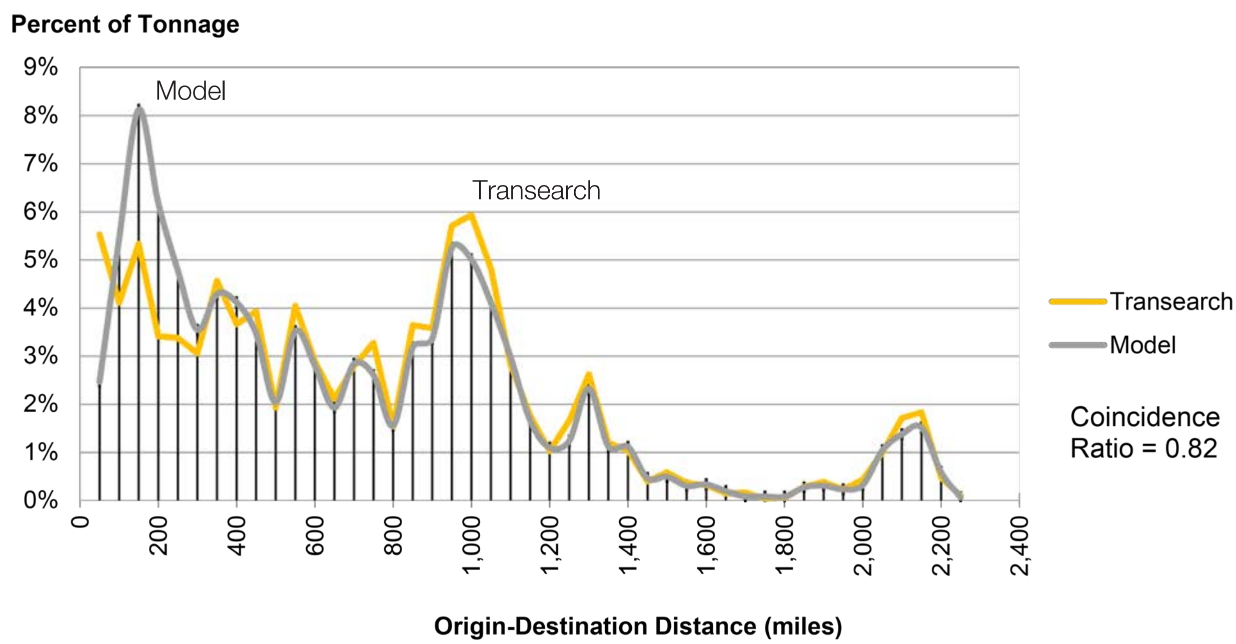

Figure 44. Chart. Miscellaneous nondurable manufacturing trip frequency plot.
(Source: Wisconsin Statewide Freight Model.)

Mathematically, the sum of the lower value of the two distributions at each increment of travel time is divided by the sum of the higher value of the two distributions at the same increment of travel time.

The procedure to calculate the coincidence of distributions is as follows:

$$Coincidence\ Ratio = \frac{Sum\left\{Min\,\frac{count_{+x}}{count_{+}},\frac{count_{-x}}{count_{-}}\right\}}{Sum\left\{Max\,\frac{count_{+x}}{count_{+}},\frac{count_{-x}}{count_{-}}\right\}}$$

Figure 45. Equation. Coincidence Ratio calculation.

Calculate for X = 1, maxX

Where:

$count_{+x}$ = value of estimated distribution at time T

$count_{+}$ = total count of estimated distribution

$count_{-x}$ = value of observed distribution at time T

$count_{-}$ = total count of observed distribution

The coincidence ratio lies between zero and one, where zero indicates that the two distributions have nothing in common and a value of one indicates two identical distributions. An example is included in figure 44.

A plot of the calibrated friction factors, scaled to a common value at the lowest impedance value provides a picture of the average sensitivity to impedance. This value can be compared to friction factors from other regions. For example, some daily recurring trips may be less sensitive to travel time and cannot be shifted to off-peak conditions or to different locations. This phenomenon can be observed in a plot where the friction factors show gradual change as travel time increases.

Significant differences between observed and estimated trip lengths may be due to inadequate closure on production/attraction balancing or issues with the travel impedances. After validating the trip distribution model at a regional level, the model results should be checked for subgroups of trips and geographic segments of the region.

Comparing trip average lengths provides a good regional check of trip distribution. However, the model can match the average trip lengths without distributing trips between the correct locations. To permit easier review of the truck trip tables, practitioners should summarize zonal interchanges at the county level, district level, or across groups of zones and compared with observed data sources (GPS traces, diaries, intercept surveys). Trips to the major employment areas in the region should also be isolated and reviewed. Major trip movements to special generators, such as ports, airports, and intermodal facilities, should be summarized as well.

K-Factors

K-factors are usually district-to-district factors that correct for major discrepancies in trip interchanges. These factors are computed as the ratio between observed and estimated trip interchanges. K-factors are typically justified as a mechanism to represent economic activity that may affect truck trip making, but is not otherwise represented in the gravity model.

K-factor use is generally discouraged and is considered a weakness of gravity models when used to correct for intangible factors. However, there are cases in freight models where productions and attractions are available only for a few interchanges (e.g., only internal productions and attractions to external productions and attractions). In these cases, K-factors can be intentionally used to prevent unintended interchanges.

Mode Split Validation

Mode split is only applicable to freight flows and freight demand that moves by multiple modes.

An aggregate validation test compares the estimated mode shares to observed shares of freight flows by different modes, such as trucks, rail, ship, and air. This test can be used as a calibration procedure that involves adjusting the modal constants until the shares match well within acceptable ranges.

If mode split analysis is performed by applying observed mode shares, independent validation is not possible.

Assignment Validation

Freight model trip assignment validation should include both passenger vehicles carrying people and commercial vehicles carrying goods. Trip assignment is the basis for validating the model's ability to replicate observed travel.

The Highway Capacity Manual (HCM) provides passenger car equivalence (PCE) factors that quantify the relative impact of different types of vehicles on congestion. The HCM recommends a PCE value of 1.5 for trucks on level terrain, with trucks defined as commercial vehicles with six or more tires and a value of 2.0 for combination units. The assignment volumes are expressed in PCEs, not in terms of the number of vehicles. Adjustments to PCE values are not needed for four-tire commercial vehicles, since these vehicles share similarities with passenger cars in terms of acceleration and deceleration capabilities.

If trucks are prohibited from using key network links, then the truck prohibitions must be part of the assignment rules in the basic network description. Four-tire commercial vehicles, such as pickup trucks and vans, are not considered to be trucks for the purposes of enforcing truck bans. Truck-only lanes should also be properly accounted for when developing the roadway network attributes. Select-link analysis methods can also be used to establish the reasonableness of truck assignments along network segments that have high levels of freight demand.

The validation tests for truck assignments are presented at three levels: systemwide, corridor, and link specific. The checks are generally made on daily volumes, but it is prudent to make the checks on volumes by time of day when possible. Systemwide checks include vehicle miles traveled (VMT), cordon volume summaries, and screenline volume summaries.

Vehicle Classification Counts

Vehicle classification counts are a source of assignment validation data. Travel demand models are validated by comparing estimated traffic volumes to observed volumes. Comparisons may be made for the entire model network by functional classification, link type, and volume ranges. Comparisons can also be made by geography focusing on comparisons at a regional level and comparisons across cordon lines and screenlines.

Vehicle classification count data typically classify vehicles according to the FHWA's 13-axle-based classes generally available from State departments of transportation for sampled sets of highways. For the 13 classes, the information includes counts by location, hour of the day, and date. In summary format, this information generally presents truck volumes defined as FHWA Classes 5 through 13 with six tires and above.

Vehicle classification count data do not distinguish between freight and non-freight vehicles or types of freight carried. Validation vehicle groups primarily consist of trucks and autos. Truck volumes may be segmented into further classes if the freight model estimates movement at a finer level of detail. The most frequent segmentation of truck volumes for validation includes medium and large trucks. Calibration of the freight model assignment process may involve adjustments to the passenger (auto) and freight model assignments.

A truck data collection program that is balanced geographically, covers all key roadways in a region, and focuses on roadways with higher truck volumes is needed to support the validation of truck traffic flows. Although there are no established rules to evaluate truck highway assignments, the principle of a lower tolerance for high volume roadways and a higher tolerance for local arterials can be used.

Similar to passenger model validation, practitioners should also be aware of issues related to the variability in coverage, quality, and availability of updated truck traffic counts. Furthermore, since traffic counts do not distinguish between freight and non-freight trucks, trip tables need to be combined and assigned to the highway network to be validated against total truck traffic counts.

Practitioners need to take a balanced approach to model validation and match truck traffic counts reasonably well in order to maintain the policy sensitivity of the developed freight model.

Model Parameters

Finally, there are parameters in an assignment model that can cause errors. Although the actual parameters and calculation options involved depend on the modeling software and assignment methodology being used, other possibilities include:

- Assignment procedures, including the number of iterations, convergence criterion, expansion of incremental loads, and damping factors.
- Volume-delay parameters, such as the Bureau of Public Roads (BPR) coefficient and exponent.
- Peak-hour conversion factors used to adjust hourly capacity and/or daily volumes in the volume-delay function.
- PCE factors for commercial vehicles.
- Scaling or conversion factors to change units of time, distance, or speed (miles/hour or kilometer/hour).
- Value of time when used to calculate generalized cost paths to account for tolling.
- Maximum/minimum speed constraints.
- Specific classes of vehicles that are preloaded to the network for assignment purposes, including high-occupancy vehicle (HOV) travel, "through trips," trucks, and long/short trips.
- Toll queuing parameters, including parameters for diversion potential.

PART D. APPLICATIONS

Part D consist of two chapters. Chapter 12 discusses issues that should be considered in each application of the methods discussed in previous chapters. Chapter 13 contains case studies that demonstrate how practitioners use the methods outlined in the *Quick Response Freight Methods* (QRFM) in real-world freight planning scenarios.

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CHAPTER 12. APPLICATIONS ISSUES

This chapter provides guidance on the effective application of the methods presented in *Quick Response Freight Methods* (QRFM). Many of these application issues are common across all forms of forecasting, while others are unique to freight forecasting. Though part C covers some of these issues as part of specific methods, this chapter discusses them as general issues that can arise in multiple methods.

The earlier sections of the QRFM discuss data collection and methods, but not all methods and data may be appropriate for a given forecast. When applying the forecasting methods discussed in this document, it is important to understand:

- The nature of the freight system in the area.
- The desired uses of the forecast.
- The availability and quality of data.
- The level of accuracy needed.
- The compatibility with non-freight (passenger) forecasts.

Freight forecasts are often a small part of larger forecasts that encompass both passenger and other non-freight truck travel. In these instances, analysts need to consider the goals of the forecast in its entirety; they should determine the level of effort for freight forecasts with an understanding of its importance within the entire forecast. For example, if freight trucks comprise five percent of the traffic volume in an area, dedicating fifty percent of available forecasting resources to freight may not be appropriate for the goals of the overall forecast. An agency's decision to develop, implement, or transition to a more advanced freight model must weigh the investment cost against the importance of answering detailed policy and planning questions.

CONTROLLING FACTORS

Controlling factors highlight the variables that analysts can change and test in the application of freight forecasts. Freight forecasting methods should be responsive to the policy and forecasting questions being asked. If analysts test changes in the size and frequency of shipments, then they should only consider forecasting methods using these variables. The forecasting process should address factors that are significant to and within the jurisdiction of the agency and the major characteristics of the alternatives.

Shipment Sizes and Frequency

Shipment size and frequency is an important factor in the shipper's choice of mode, but these business process decisions vary markedly across industries, are subject to continuous and unpredictable changes, may be outside the jurisdiction of public agencies, and may not be addressed by public agency projects or programs.

Some modes of freight transport may only be appropriate when the shipping distance exceeds several hundreds of miles. For a metropolitan area that covers a radius of less than 100 miles, those modes may need to be handled separately or excluded from the agency forecasting methods. If the actions of the agency are likely to impact mode choice for freight, the forecasting process should cover a broader area than passenger forecasts. Covering a broader area has implications on the development of a network or forecast.

Operational and management plans often require forecasts for a shorter time period than the typical 20-year horizon considered by planning agencies. Pavement management systems require freight forecasts to be sensitive to seasonal variations that analysts rarely consider in forecasting processes. In these cases, growth factoring methods may provide better short-term forecasts that are sensitive to seasonal demand.

Reliability

Reliability for the agents of demand considers the ability to meet required delivery windows between origins and destinations. The agents transporting freight and the agents for non-freight trucks measure the route reliability on the network (e.g., the 95^{th} percentile travel time on a link).

Congestion

Freight forecasts should consider all demand that contributes to network congestion if congestion and associated delay is a desired output measure (e.g., freight and passenger demand). Congestion has varying impacts depending on the commodity being transported; bulk commodities are relatively insensitive to transport times, while perishable commodities are extremely sensitive to time.

Resiliency

The shipper receiver agents making decisions on the freight cargo demand consider resiliency in a different manner from carrier agents. Resiliency for shipper carrier agents connotes alternative modes, supply chains, or routes, while the routing decision makers consider the resiliency of the paths on the modal networks on which they operate.

These are few examples of how understanding the controlling factors can influence the selection of a freight forecasting method. If an agency does not consider these factors, it risks expending scarce resources on developing a method that does not consider the desired policy and project attributes, considers attributes that will not change, or relies on forecasts that will not be available.

DATA COLLECTION

Availability of data for freight and non-freight truck forecasting influences the methods that agencies use to prepare those forecasts. Commodity freight equations are not easily transferred between regions, and methods to forecast freight demand depend on the local economy, demographics, and modes that are available. Unless resources are available to obtain or collect freight data, many methods may not be appropriate.

Sharing data through cooperative partnerships between agencies and other organizations is a cost-effective method to obtain data. Partnerships with regional stakeholders are a place to start, as they benefit directly from the freight modeling program; partnering with other agencies that also develop and maintain freight modeling programs is another option. It is increasingly common for metropolitan planning organizations (MPOs) to co-fund large data collection efforts. Establishment surveys that collect either origin-destination data or driver diary data can be resource-intensive and partnerships with adjacent MPOs provide an excellent opportunity for shared data collection for freight.

APPLICATION OF QUICK RESPONSE FREIGHT METHODS

Freight forecasts are used in many applications. Detailed models support Traffic Impact Analyses (TIAs) or Environmental Impact Studies (EISs) for specific facilities (e.g., terminals or network links) and State freight plans and long range transportation plans. This document describes methods ranging from the application of growth factors to the development of sophisticated supply-chain models. These freight forecasting methods are unlikely to have forecasts both within and without a facility, which is the focus of the TIA/EIS. Freight methods used in research applications may not require integration with passenger forecasts. Research applications focus on the relative change between alternatives rather than detailed forecasts used to develop long range plans. Operational applications typically require forecasts of demand for more detailed time periods (e.g., demand that varies by hour) than the average daily demand that QRFM methods can support.

GROWTH FACTORING

Growth factoring methods rely on trends in historical flows or economic indicators and assume that the trends will continue going forward. More sophisticated forecasting methods should be considered when these assumptions are not valid.

Growth factoring cannot forecast activity if there is no freight activity in the past, which is a basic shortcoming of this method. In situations where new freight activity is expected and not just an extension of existing trends, analysts should explore alternative methods.

If analysts expect an underlying change in the freight activity then growth factoring may not be appropriate. An example of an underlying change is if analysts develop growth factors using a period of economic regulation of freight carriers for a forecast period without this economic regulation.

The use of economic indicator variables in factoring has additional issues, in addition to the application issues associated with extending past trends. Developing the relationship between freight flow and the economic indicator variables may be difficult. Truck count data, is used in forecasting trends, may be available only in the aggregate and provides no information about underlying purposes or commodities. Total truck volumes may be known, but flows by commodity are unknown or difficult to obtain and average usage assumptions may not be appropriate.

NETWORK AND ZONE STRUCTURE

The ability to use sophisticated methods to forecast freight is constrained by the network and zone structure available to support the analysis. Regardless of method, the agency's geographic area may be too small to address the distances or cover the markets required for freight/truck forecasting. Supply chain freight models often include a large geographic scale to accurately capture freight movement as part of a global system.

Once the agency identifies the model area, the analyst should obtain base- and forecast-year data for that zone structure. In many cases, the data available for the zone structure includes the geography outside of the immediate model area dictating the zone structure. For example, a freight model for New York City may contain a single zone covering the State of Florida and a sparsely detailed network within Florida. The size of zones does not have to be dictated by the zones in a data source. Zones can be combined if their impacts on the focus area of the model is not expected to be significant. Reducing the number of zones can reduce the cost and complexity of a freight model.

DEVELOPING AND ASSIGNING TRIP TABLES

Forecasting the transport of freight on modal networks and of non-freight trucks on highway networks involves assigning a trip table of demand to a network of supply. The agents (i.e., shipper and receiver pairs) that make decisions concerning the freight demand differ from the agents (i.e., carriers) use and generate demand that is assigned to modal networks.

Trip Generation

Practitioners may create trip generation equations using the regression of an independent variable (often employment by industry) to a survey of the dependent variable, observed base year flows (likely a commercial vehicle survey) for truck type models, and a commodity database for multimodal commodity models. If the rates are transferred from an existing model, analysts should assume that the conditions giving rise to the trip generation equations are similar enough to the study region to make transference appropriate.

For non-freight methods where the trip purposes are trucks by size, the production equations are typically the same as the attraction equations, since the number of trucks entering a zone will equal the number of trucks leaving that zone. For models where the purpose is a commodity, there are separate equations for productions and attractions. The independent variable in a commodity production equation likely relates to the industry producing that commodity and the attraction industry relates to the industries consuming that commodity.

Commodity models developed from surveys of unlinked trips (e.g., TRANSEARCH) where the survey includes a separate record for each modal portion of a multimodal trip, analysts cannot explicitly calculate the change of mode in the forecast. In these instances, the traffic originating in or destined for zones that contain intermodal terminals is specifically reported. These zones need to be handled as special generator zones in the trip generation process. Forecasts for these special generators should be obtained from other sources such as the facility operators.

Trip Distribution

Most freight trip distribution methods use a form of the gravity model. Freight modeling often uses an exponential form of the impedance function. The use of the exponential form of the impedance function provides a check on the coefficients used in freight trip distribution. The impedance or friction factor between zones *i* and *j* is of the form shown in figure 46.

$$F_{ij} = e^{-k * t_{ij}}$$

Figure 46. Equation. Gravity model friction factor equation.

Where the k-coefficient in that exponential distribution is the inverse of the average trip length expressed in the travel units, usually time or distance, measured by t_{ij}.

When the travel unit is minutes and the coefficient is 0.08, the implied average travel time is 12.5 minutes (12.5=1/.08). For freight models, the average trip length is typically used; for example, a mean shipping distance of 526 miles for metallic ores has a coefficient of -0.0019 (1/526). An average distance of 526 miles, a longer distance than most passenger models can support, illustrates why freight models may require larger networks, well beyond the study area focus, simply to forecast the behavior of freight in the study area. The freight networks and zones will be larger than the typical networks from passenger models.

In passenger forecasting, the result of the trip distribution process is a production-attraction table that is later factored into an origin-destination table to ensure that the trips between the origin and destination are balanced. Passenger trips starting at the home must return to the same home zone at the end of the day. Freight modeling does not need to account for balancing, since freight travel is not a balanced procedure. The result of a freight trip distribution is in an origin-destination format. A shipment of metal products from a factory does not return to the factory, but instead used by the receivers of those metal product shipments.

Mode Choice

Freight forecasting requires mode choice, but non-freight truck forecasting is explicitly one mode. Trip-based methods often rely on the existing demand from the existing model shares. These reported mode shares are specific to regions and are not transferable to other regions. Supply chain choice is analogous to mode choice, except that a supply chain may comprise multiple modes. The structural equations for supply chains are transferable, but it is unclear that the coefficients for the supply chain models or the equations themselves should be transferred.

Conversion to Vehicles

Forecasts are calculated in non-mode specific flow units, such as tons, ton-miles, or value of shipments. To be useful in many transportation forecasting applications, analysts need to convert flow units from annual tons to daily vehicles: trucks are common and rail cars are less common.

While the Census Bureau has not collected the Vehicle Inventory and Use Survey (VIUS) since 2002, it remains one of the few sources that can be used to estimate payloads for the commodity-specific contents of the truck. Use of VIUS is predicated on the assumption that commodity carrying characteristics have not changed with respect to truck payloads. Vehicle payloads by commodity can be transferred for use elsewhere, but these are national averages and do not reflect the payloads in a particular region. VIUS also includes information on the percentage of empty truck-miles, so VIUS-derived payloads include allowances for empty miles.

The conversion from annual tons to daily tons is based on local considerations about how an average day is included in transportation forecasting. Typically, this number is based on the number of working days per year during which freight is expected to move. Analysts commonly use values such as 312 days per year (six days per week), 306 days per year (six days per week less six major holidays), 250 days per year (five days per week), or 296 days per year (derived from reported counts as reported in NCFRP Report 8). This consideration may also reflect seasonal variations.

Assignment of the Demand Table

Freight demand assignment typically refers to freight and non-freight truck assignments on highways. Other modal networks are either privately-owned (e.g., railroads) where business decisions determine the assignment or networks where path choices are limited (e.g., inland waterways).

Freight truck highway assignments may be performed as a preload, where truck trips are pre-assigned to links before the passenger auto trips are assigned or the network at the same time as passenger auto trips. Depending on the assignment method and features of the modeling software used to assign the table, each method has advantages and disadvantages.

There are valid conceptual considerations for pre-assigning truck trips: The drivers of large long-haul freight trucks may be unfamiliar with alternate routes in the event of congestion; combination and tandem trucks may not be able to maneuver on the arterial and collector roads on alternate paths; or truck companies/drivers may value reliability more than travel time and chose reliable times on congested routes over variable time on faster alternate routes.

Assigning truck trips with passenger auto trip tables in a multiclass assignment is appropriate when trucks are expected to respond to congestion in a manner similar to autos. This is appropriate when most truck drivers are familiar with alternate paths or congestion introduces unreliable conditions rendering all paths suitable for trucks. It is still possible in these multiclass assignments to restrict trucks from portions of the network with truck prohibitions. In a multimodal assignment, both trucks and autos modify their paths in response to congestion.

Static traffic assignment methods require that practitioners report tables of demand as trips rather than tours. For supply chain tour models, which consist of several trips within a single tour, this requires unlinking the tour into individual trips. The rosters of tour forecasts are averages and do not directly provide departure time needed for the dynamic traffic assignment.

Analysts typically do not assign vehicles for modes other than trucks; when they do, the assignment may use a predetermined set of paths between an origin and a destination that does not vary due to congestion. Analysts often take this approach in forecasting rail flows. Using a predetermined set of paths means that analysts can consider the private business decisions of the modal operators, where paths may be chosen to balance loads, maximize system revenue, provide incentives to favored shippers, or optimize the paths for a specific shipment or user. However, these paths are usually obtained through qualitative examination instead of quantification based on characteristics of the links on the path.

INTEGRATION WITH PASSENGER FORECASTS

Most of the assignment application concerns involve integrating freight and non-freight truck forecasts into the highway model. The creation of the table of freight and non-freight truck demand is separate from passenger forecasts, and the integration of passenger with freight/truck methods occurs in assignment to the shared highway network.

There is assignment overlap for light, four tire trucks used for personal or commercial purposes. Traffic counts used to validate assignments cannot distinguish between personal and commercial uses of these vehicles. The behavior of light trucks in commercial purposes and passenger vehicles used for non-home-based (NHB) passenger trips share similarities. Practitioners preparing forecasts need to determine if light vehicle commercial trips should be considered with NHB trips.

A similar application concern is integrating commodity freight truck models with passenger auto forecasts. In these models, the definition of freight may exclude local deliveries of freight and those local delivery truck trips are not included in the passenger forecasts. The validation data does not distinguish between trucks used in freight and trucks used for other purposes such as service, construction, utility, and local delivery. Freight model practitioners need to reconcile the forecasted truck types with the available count data for validation purposes.

VISUALIZATION

Understanding and communicating the significance of freight data is critical to planning for future transportation capacity, operation, preservation, safety, security, energy, and economic investment needs. The advent of new data sources and more robust analytic tools does not change the importance of turning data into information and allowing that information to inform decisions. The recent explosion of data available increases the importance of separating the signal from the noise, both in terms of performing data analysis and summarizing actionable intelligence. Using visualization techniques to tell a compelling story is a hallmark of new data and analytic applications, and it can be applied to freight forecasting as well.

Transportation agencies can enhance their freight transportation planning and decision making by using visualization tools to provide a powerful means of communicating complex concepts and data. Visualization tools provide a means of communicating freight performance measures, helping freight stakeholders understand geographic information such as truck touring routes; temporal information such as time of day delivery patterns or seasonal variability; and physical information such as the effect of alternative curb space management approaches on goods delivery.

Practitioners can use visualization techniques to develop robust forecasting models that allow staff to quickly check the quality of the data and identify potentially erroneous results. Visualization helps explain a variety of freight-related variables that may be inputs to or outcomes from an analytic technique, providing a "common language" to promote a greater understanding and more productive dialogue among modelers, planners, researchers, the private sector, decisionmakers, and other stakeholders.

Freight and non-freight truck forecasts of tables of demand or network flows are available in tabular from. Researchers have developed visualization techniques to agencies analyze these forecasts. These techniques are presented in https://www.nap.edu/catalog/24755/data-visualization-methods-for-transportation-agencies.

Figure 47 presents tables of demand using Freight Analysis Framework (FAF) data prepared by the Brookings Institute. This figure presents the FAF flows as chart of flows between FAF regions. This type of visualization can be presented for any of the forecast trip tables of demand developed using the QRFM. These may display flows between zones or summaries of zones, but only for certain commodities or mode/supply chains.

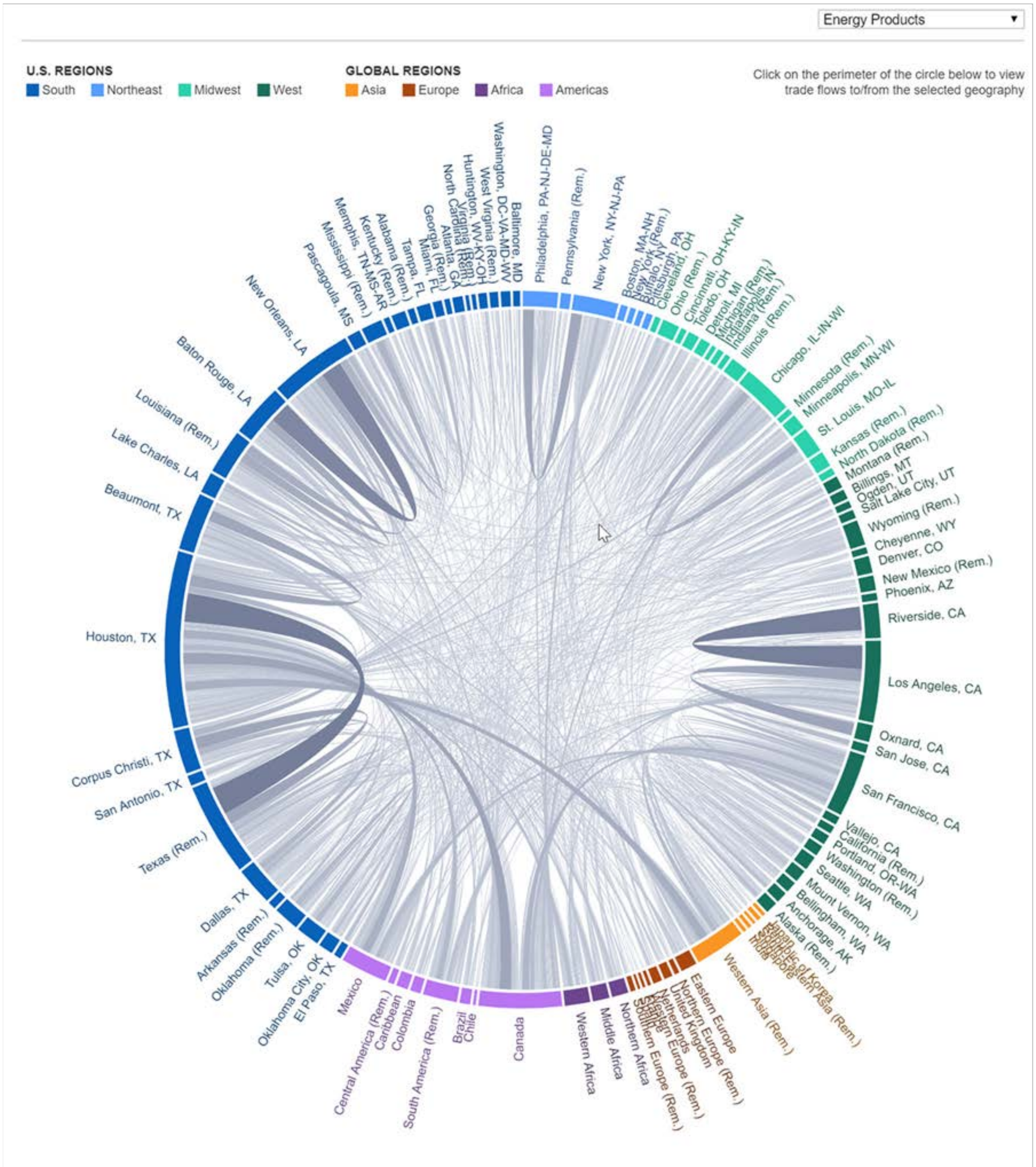

Figure 47. Diagram. Energy Product Flows.
(Source: http://www.brookings.edu/research/reports2/2015/06/metro-freight.)

The Maricopa Association of Governments (MAG) uses three-dimensional visualization methods to present freight data, shown in figures 48 and 49.

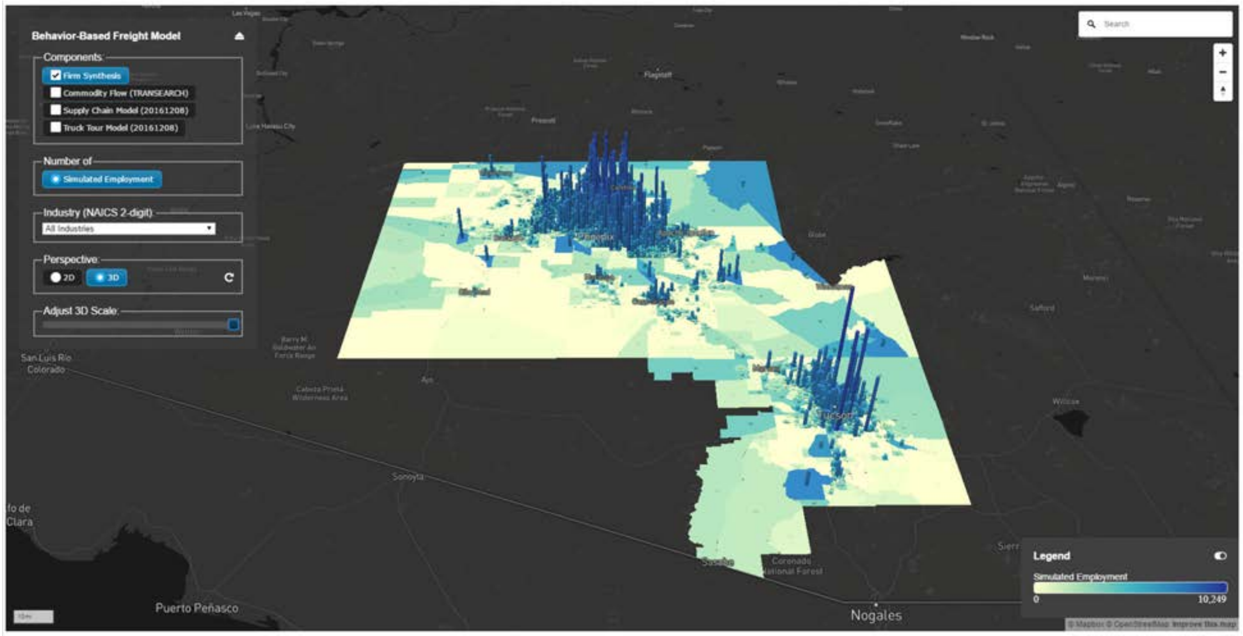

Figure 48. Screenshot. MAG firm synthesis visualization.
(Source: MAG.)

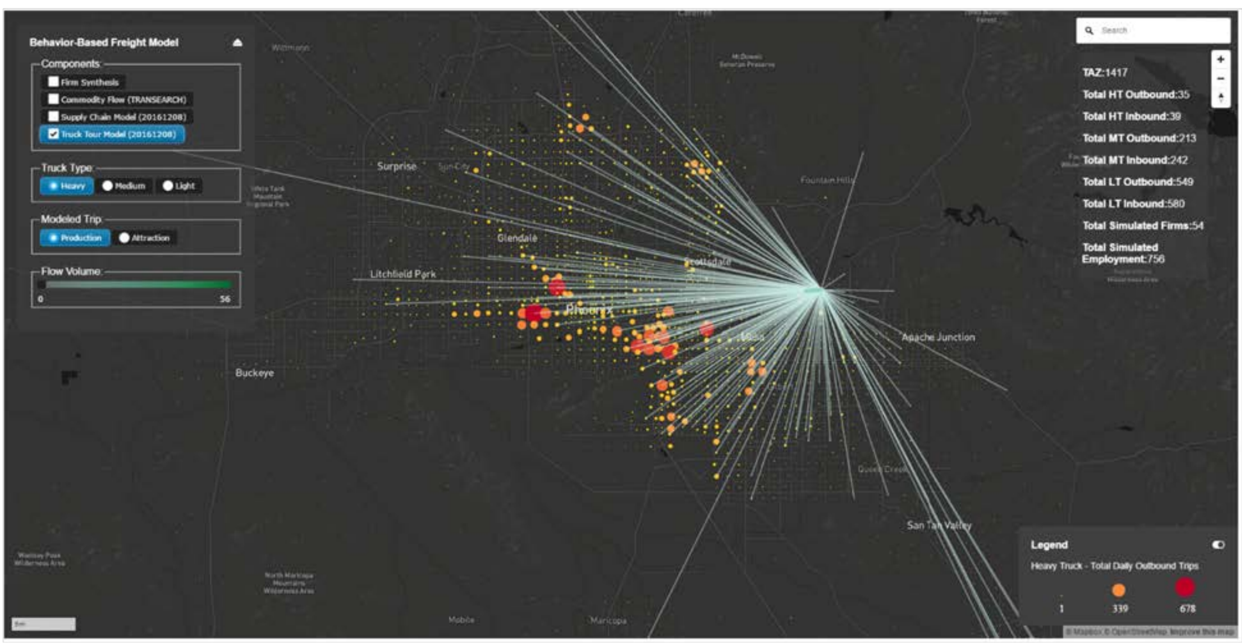

Figure 49. Screenshot. Commodity flow visualization (supply chain model).
(Source: MAG.)

CHAPTER 13. CASE STUDIES

Six case studies were selected to illustrate how freight forecasting methods are applied. These case studies represent a variety of methods, geographies, and estimation data; they are meant to highlight how agencies address application issues and they are not endorsements of the approaches described.

This chapter presents the case studies in the following format.

CASE STUDY NAME

The case study name provides the name of the case study and the title of the freight model or modeling process used for freight forecasting. This chapter presents the following case studies:

- California Statewide Forecasting Model.
- Florida Department of Transportation Model.
- Iowa Department of Transportation Statewide Traffic Analysis Model and Freight Optimization Model.
- Maricopa Association of Governments Model.
- Memphis Metropolitan Planning Organization Truck Model.
- New York Metropolitan Transportation Council's Best Practices Model.

Introduction

This section includes a brief background of the agency for the case study. The introduction provides basic information on the agency and identifies informational items such as agency responsibilities, jurisdiction, and the importance of freight to the area.

General Information

Usage

Freight forecasts have a variety of uses, including research, freight planning, project design, impact studies, and the production of required documents including long range transportation plans (LRTP), transportation improvement programs (TIP), and air quality (AQ) determination.

Methodology

The method(s) used, according to those outlined in Part C of the *Quick Response Freight Methods* (QRFM), include the following:

1. Existing forecasts prepared by others.
2. Factoring forecasts.
3. Commodity forecasts: a commodity freight trip table acquired from others and integrated into an existing forecasting process.
4. Trip based methods:

a. Freight four step models; trip generation (TG), trip distribution (TD), mode choice (MC)/mode share (MS), and trip assignment (TA) model components.
b. Non-freight three step models: TG, TD, and TA.

5. Supply chain/tour methods:

a. Freight: Trip tables of demand created by agents prior to supply chain choice are typically disaggregated from an existing forecast (e.g., the Freight Analysis Framework [FAF]) that is then aggregated for all supply chains.
b. Non-freight trucks: Tour models estimated for non-freight trucks.

Coverage

Geography

The geographic coverage for freight is discussed. It includes either external zones outside of the study region or national estimation data windowed to external stations. Imports and exports are most often a trade type, not a geography. Non-freight is typically smaller in scale than the freight geography and confined to the immediate study area.

Modes

Freight modes consist of truck, rail, water, air, multimodal, pipeline, or other/unknown modes. Multimodal freight may or may not distinguish between rail-truck and other multiple modes. Non-freight trucks may be split be truck size (e.g., medium and combination trucks). Empty freight trucks may be included as non-freight trucks.

Commodities

The commodity classification used in the case study is described. It may include Standard Transportation Commodity Classification (STCC), Standard Classification of Transported Goods (SCTG), and commodity group aggregations of other systems.

Forecast Details

Freight Trip Table

The process used to forecast the trip table of demand using one of the outlined methods or combination of methods is discussed.

Non-Freight Trip Table

A description is provided for the development process for a table of non-freight truck demand.

Modal Network Assignment

A description is given of how practitioners assign the origin-destination (O-D) table of demand to the networks on which the modes operate. This section provides a description of the modal networks that are used and documents the type of assignment process and the capacity units. If available, it also describes the use of truck restrictions or prohibitions.

CALIFORNIA STATEWIDE FREIGHT FORECASTING MODEL

Introduction

California leads the United States as the largest freight destination by value. California is a major multimodal gateway and hub for global trade. With an extensive freight rail network, California is home to significant international freight gateways for goods movement by water, air, and truck.

Three of the five busiest ports in the United States are located in California, including the San Pedro Bay Ports (SPBP) complex. The SPBP complex, comprising the Port of Long Beach and Los Angeles, leads the Nation's freight activity and is one of the top ten busiest container port complex in the world. The SPBP complex is an important contributor to both California's and the Nation's economies. In 2015, the SPBP accounted for about 18 percent of North America's market share and handled over 38 percent of container throughput in the U.S.

Los Angeles International Airport is the fifth busiest airport in the Unites States by total cargo throughput, and the nearby Otay Mesa Land Port of Entry (LPOE) is the fourth busiest land port in the United States. This region is also home to the Southern California Association of Governments (SCAG), the Nation's largest metropolitan planning organization (MPO), which represents six counties, 191 cities, and more than 18 million residents.

Significant environmental costs have accompanied the State's trade boom. California has been a leader in adopting various strategies and regulations to mitigate CO_2 and Greenhouse Gas emission. The California Transportation Plan (CTP) and California Freight Mobility Plan (CFMP) are required to review and identify integrated multimodal transportation system options to address how emissions reductions would be achieved. These regulations and policies make it crucial for the State of California to have the tools necessary to analyze different economic, social, and environmental policies associated with goods movement. One of the key strategic responses by the California Department of Transportation (Caltrans) to this issue is the development of the California Statewide Freight Forecasting Model (CSFFM 1.0) in 2007.

CSFFM is a policy-sensitive tool that forecasts multimodal vehicle and commodity flows within California. CSFFM is designed using the Citilabs CUBE software platform. The model addresses socioeconomic conditions, freight-related land use policies, environmental policies, and multimodal infrastructure investments. The model comprises seven core modules: the disaggregated data preparation, commodity flows, mode-split, transshipment, seasonality and payload factors, non-freight truck, and network assignment modules.

Over the years, CSFFM was updated and improved. The latest version, CSFFM 3.0 is integrated with the California Statewide Travel Demand Model (CSTDM) and is calibrated and validated for the years 2015 with forecasts for 2020, 2040, and 2050.

General Information

Usage

CSFFM is a multimodal commodity-based model. The 15 commodity categories are assigned to four heavy duty truck classes based on Gross Vehicle Weight Rating (GVWR) (C1: 10k-14k lbs, C2: 14k-26k lbs., C3: 26k-33k lbs. and C4>33k lbs). The model is designed to be used by State agencies, such as Caltrans, the California Air Resources Board, the California Energy Commission, and regional agencies, including MPOs and regional transportation planning Agencies (RTPA). CSFFM uses a policy-sensitive model design for forecasting commodity flows and commercial vehicle flows within California. The model can be used to address diverse issues, like socioeconomic conditions, land use policies related to freight, environmental policies, and multimodal infrastructure investments.

The integrated CSTDM/CSFFM model can also be used by State and regional agencies and actors, such as:

- Planners and engineers in Caltrans district offices.
- Other State agency staff (i.e., California Air Resource and the California Energy Commission).
- Regional planners in MPOs and RTPAs (i.e., Southern California Association of Governments and Sacramento Area Council of Governments).

With a policy-sensitive design, the integrated CSTDM/CSFFM forecasts commodity flows and commercial vehicle flows within California. The integrated Model addresses various scenarios for the 2019 California Freight Mobility Plan and 2020 California Transportation Plan, including:

- The impact of various policies on regional land inter-regional vehicle miles traveled (VMTs).
- Socioeconomic conditions.
- Land use policies related to freight.
- Environmental policies.
- Multimodal infrastructure investments.

Methodology

CSFFM is a four-step commodity-based model capable of capturing high-level interactions between various industries. Using the Freight Analysis Framework, Version 4 (FAF4) as a key data source, CSFFM can also capture supply chains to estimate commodity flows. The flow between the six California FAF4 zones are disaggregated to Freight Analysis Zones (FAZs), gateways, and intermodal facilities.

An overview of the model is shown in figure 50. The outputs of the model are categorized by truck flows according to vehicle class, rail tonnage flows at the network level, and air, water, and pipeline tonnage flows at the O-D matrix level, as represented in figure 50.

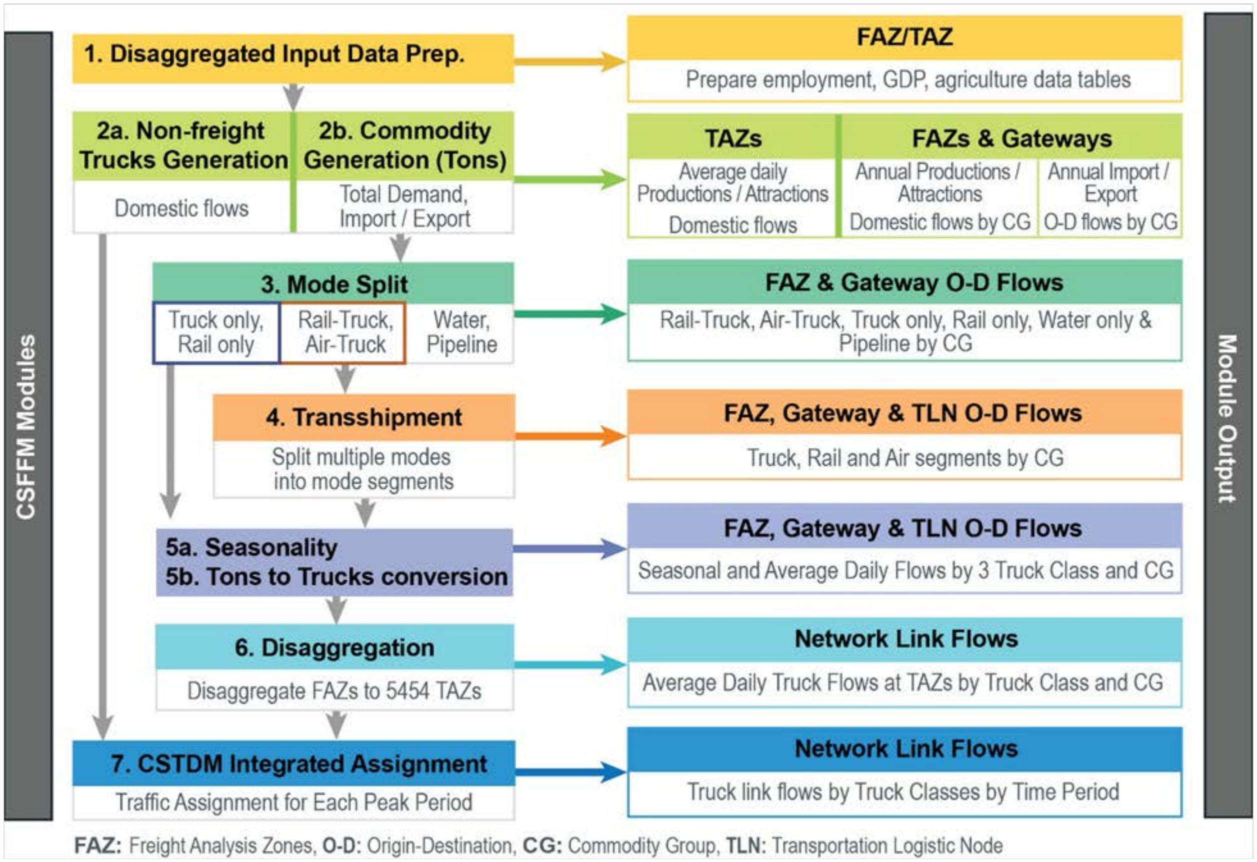

Figure 50. Flowchart. California Statewide Freight Forecasting Model 3.0 architecture. (Source: Integrated CSTDM/CSFFM model.)

CSFFM Modules interact with one another to create comprehensive and contextual outputs. The Modules are described below:

- **The Commodity Module** consists of total generation, domestic flow distribution, and import/export gateway distribution. This module produces commodity production, attraction, and distribution based on demographic and economic data and impedance information (i.e., travel time and cost).
- **The Mode Split Module** determines the mode share for each mode in each origin-destination pair. Incremental logit models are used in this module to evaluate the impact of changes in mode attributes.
- **The Transshipment Module** breaks intermodal trips into segments by mode and assigns commodity flows at the transport logistics nodes (TLNs).

- **The Payload Module** uses truck tonnage, multimodal information, and truck flows from transshipment facilities and generates average daily flows by four truck classes for each commodity group.

- **The Disaggregation Module** disaggregates the FAZ's O-D matrix for each commodity to 5,454 traffic analysis zones (TAZs).

- **The Non-Freight Truck Trip Generation Module** generates the "non-FAF" truck flows between TAZs. Non-FAF truck flows include empty trucks, service trucks, utility trucks, construction and moving trucks, local delivery trucks, or any other type of truck flows that, by definition, are not included in the FAF database.

- **The Network Assignment Module** consists of route choice and traffic assignment. This module uses multiclass user equilibrium assignment to assign trucks to the road network and all-or-nothing for the rail assignment.

Coverage

Geography

CSFFM comprises 97 FAZs within California that are defined at the county and subcounty levels. FAZs, as shown in figure 51, conform to MPO and air basin boundaries. There are 38 import/export gateways (19 land ports, 8 airports, and 11 seaports) and 31 TLNs (13 airports and 18 rail terminals, including 5 virtual rail terminals) within California. Outside of the State, the scheme includes 118 domestic regions that conform to the FAF zones. In total, there are 264 zones in CSFFM. Multimodal commodity flow matrices are estimated between these. Truck flows from CSFFM are disaggregated to 5,454 TAZs in CSTDM, and the integrated multimodal user equilibrium assignment will assign trucks to truck routes on State highways, Interstate highways, and major arterials.

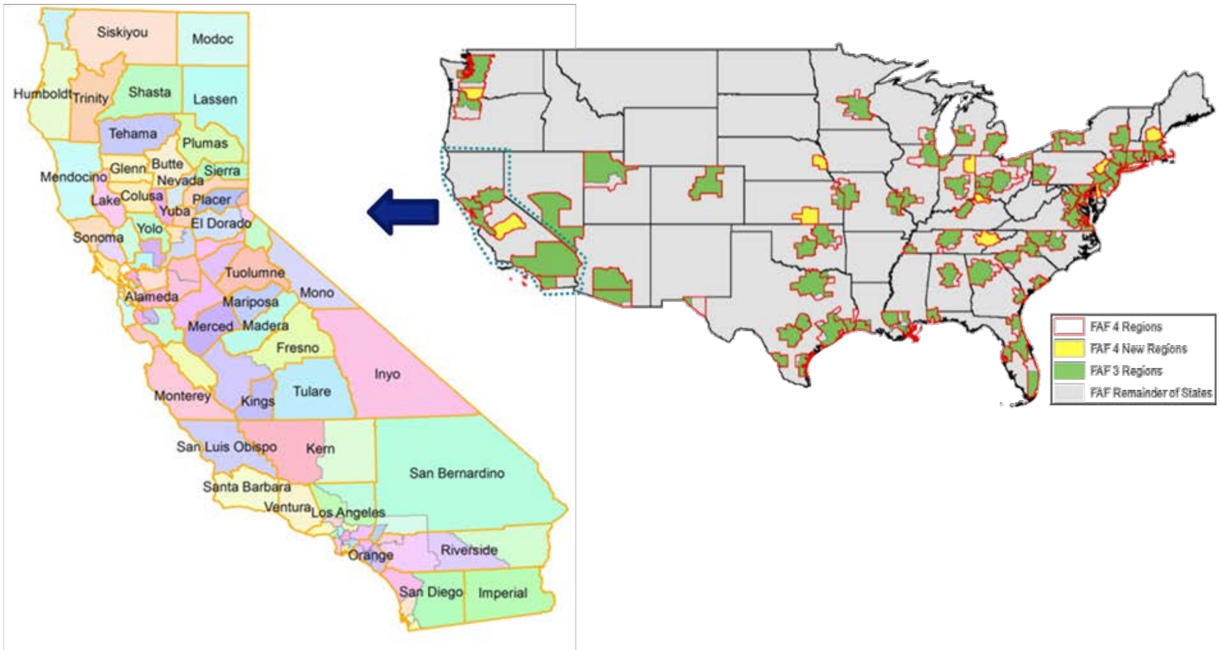

Figure 51. Map. Freight analysis zones in California and the rest of the U.S.
(Source: Integrated CSTDM/CSFFM model.)

International gateways are represented in CSFFM by nodes of entry or exit for freight movements both to and from California. Mexican border gateways in Arizona are also included because commodity flows passing through those gateways by truck or rail directly affect freight movements in California.

Modes

Eight gateway airports that handle international air cargo and eleven gateway seaports were identified, based on 2015 annual flow tonnages found in the U.S. Army Corps of Engineers Waterborne Commerce data. Nineteen mode-specific land ports were defined from the 2015 BTS TransBorder Freight Database, including eleven land ports for truck mode and eight ports for rail mode. Since some of these land ports are co-located in bimodal gateways, they are represented in twelve distinct gateways, six of which are in Arizona. CSFFM gateways are included in figure 52.

No	Seaport
1	Port of San Diego
2	Port of San Francisco
3	Port of Redwood City
4	Port of Humboldt
5	Port of Oakland
6	Port of Richmond
7	Port Hueneme
8	Port of Los Angeles
9	Port of Long Beach
10	Port of Stockton
11	Port of Sacramento

No	Airport
1	San Diego International
2	San Francisco International
3	Oakland International
4	Fresno International
5	Los Angeles International
6	Long Beach Airport
7	Ontario International
8	March ARB

No	Land port	State	Land Port
1	Tecate	California	truck/rail
2	Calexico	California	truck/rail
3	Calexico-East	California	truck/rail
4	San Ysidro	California	Rail
5	Douglas	Arizona	truck/rail
6	Naco	Arizona	truck/rail
7	San Luis	Arizona	truck/rail
8	Nogales	Arizona	truck/rail

No	Truck port	State
1	Otay Mesa	California
2	Andrade	California
3	San Ysidro	California
4	Lukeville	Arizona
5	Sasabe	Arizona

Figure 52. Diagram. California Statewide Freight Forecasting Model gateways.
(Source: Integrated CSTDM/CSFFM model)

Commodities

CSFFM includes fifteen commodity groups (CGs) based on the aggregation of the two-digit Standard Classification of Transported Goods (SCTG) commodity classes used by FAF. Commodity groups are shown in table 40 below.

Table 40. Association of standard classification of transported goods codes with commodity groups.

Commodity group	2-digit SCTG
CG-1: Agricultural products	1-4
CG-2: Wood and paper products	26-29
CG-3: Crude petroleum	16
CG-4: Fuel and oil products	17,18,19
CG-5: Gravel, sand and nonmetallic minerals	10-13
CG-6: Coal and metallic ore	14-15
CG-7: Food, beverage, tobacco products	5-9
CG-8: Manufactured products	24,30,39,40,42,43
CG-9: Chemical, pharmaceutical products	20-23
CG-10: Nonmetal mineral products	31
CG-11: Metal manufactured products	32-34
CG-12: Waste material	41
CG-13: Electronics	35,38
CG-14: Transportation equipment	36-37
CG-15: Logs and Lumber	25

Forecast Details

Freight Trip Table

Production and consumption of each commodity group are modeled simultaneously. Each commodity group is associated with production- and consumption-dependent variables, which are all estimated simultaneously. This is accomplished by considering direct correlation and causal effects defined in a confirmatory manner using path analysis in Structural Equation Modeling (SEM) framework. The general formulation of the model is shown in figure 53.

$$\begin{cases} P_i^m = \sum_k \beta X_{ik} + \gamma P_i^n + \delta C_i^n + e_{mi} \\ C_i^m = \sum_k \beta X_{ik} + \gamma P_i^n + \delta C_i^n + e'_{mi} \\ \mathrm{cov}(X_k, X_l), \mathrm{cov}(e_m, e_n), \mathrm{cov}(e_m, e'_n), \\ \mathrm{cov}(e'_m, e'_n), \mathrm{cov}(P_i^n, e_m), \mathrm{cov}(C_i^n, e'_m) \epsilon R \end{cases}$$

Figure 53. Equation. Production and consumption equations and explanatory variables.

Where P_i^m and C_i^m represent the production and consumption of commodity group *m* in zone *i*. X_{ik} are exogenous socioeconomic or industrial related explanatory variables and β,γ and δ are calibration parameters. e_{mi} and e'_{mi} are unobserved error terms in the production and consumption equations.

The model does not assume independence between explanatory variables (indicators) and error terms. The general formulation of Structural Equations for Multi-Commodity O-D Distribution Model (SEMCOD) presented in figure 54 is a second order log-linear model, or translog model.[13]

$$\begin{aligned} Ln(f_{ij}^m) = & \underbrace{\sum_l \beta_l^m Ln(X_{il})}_{\{origin\ variables\}} + \underbrace{\sum_k \gamma_k^m Ln(X_{jk})}_{+\{destination\ variables\}} + \underbrace{\sum_l \sum_k \delta_{lk}^m Ln(X_{il}) \cdot Ln(X_{jk})}_{+\{interaction\ variables\}} + \underbrace{\sum_{n \neq m} \gamma^n Ln(f_{ij}^n)}_{+\{relationship\ with\ other\ commodities\}} \\ & \underbrace{+ \lambda^m Ln(dist_{ij})}_{+\{distance\ funciton\}} \underbrace{+ \mu^m U_{ij}^m}_{+\{utility\ function\}} \underbrace{+ \varepsilon_{ij}^m}_{+\{error\ term\}} \end{aligned}$$

Figure 54. Equation. Commodity flows equation and explanatory variables.

[13] A Structural Direct Demand Model for Inter-Regional Commodity Flow Forecasting, Fatemeh Ranaiefar, Joseph Chow Michael McNally, Stephen Ritchie, TRB, 2013.

Where f_{ij}^{m} is the flow of commodity group m from zone i to zone j. X_{il} is the set of demo-economic attributes of the origin zone. X_{jk} is the set of demo-economic attributes of the destination zone. $Ln(X_{il})\cdot Ln(X_{ik})$ is the O-D interaction term for different demo-economic variables. $dist_{ij}$ is the distance between the origin and destination, and U_{i}^{m} is a logsum of the generalized cost of transportation between the origin and destination for all available modes of transportation for every commodity group. For intra-zonal flows, $dist_{ii}$ is a measure of the size of the zone, and U_{ii}^{m} is a measure of the generalized cost of transportation in zone i. Based on the FAF[4] data, 98 percent of intra-zonal commodity flows are transported by truck, so U_{ii}^{m} is defined as the log of average cost of transporting 1 kiloton of commodity m for the average trip length in zone i. $\sum_{n\neq m}\gamma^{n}Ln(f_{i}^{n})$ measures the cross effect of other industries on the commodity flow of group m. $\beta,\delta,\gamma,\lambda,\mu$ are the parameters of the model and are estimated via Maximum Likelihood.

SEMCOD is an interregional multi-commodity flow distribution model based on a spatial econometric interaction model (or direct demand distribution) in the SEM framework. Because SEM is a confirmatory modeling approach, the fitness depends heavily on the knowledge obtained during the data mining process in the data preparation phase. All O-Ds do not follow in the same pattern or share the same characteristics. Also, proper treatment of zero-cells is required to ensure the consistency of estimates. Consequently, it is not possible to estimate a single model for all O-D pairs. Thus, the O-Ds are grouped into multiple clusters. One of the advantages offered by this model is this flexibility to cluster, which are described below:

1. **Intra-zonal flows** include flows within each FAZ in California/FAF zones outside California.
2. **Medium haul flows** are flows between neighboring zones or zones with a maximum distance of 500 miles based on the road network.
3. **Long haul flows** comprise flows between zones with distance between 500 and 1500 miles.
4. **Long Interstate flows** include flows with distances greater than 1500 miles.
5. **Special generations** are flows from/to major warehouses, distribution centers, trans-load facilities.

Import and export flows are modeled implicitly. Total imports and exports are exogenous to the model and provided as an input. An example of an imported manufactured product's path is provided in figure 55. The domestic modal distribution of imported and exported commodities are modeled based on available modes between each O-D pair and the international gateway of entry. A lack of disaggregated observed data limits the capability of this module.

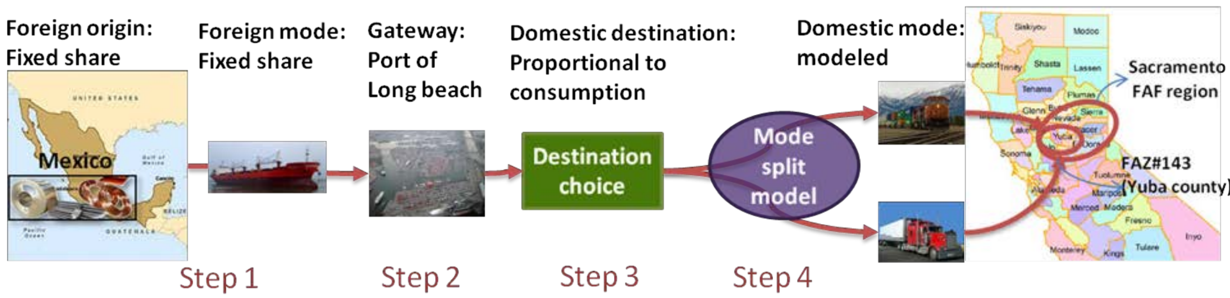

Figure 55. Diagram. Example: import of manufactured product.
(Source: Integrated CSTDM/CSFFM model.)

The Mode Split Module comprises incremental logit models for truck-only, rail-only, multimodal and fixed-factor models for pipeline, parcel, air-truck and domestic waterways. The FAF contains mode flow information for seven mode categories: truck, rail, water, air, multiple modes and mail, pipeline, and other and unknown. This information used to develop the Mode Split Module shown in figure 56.

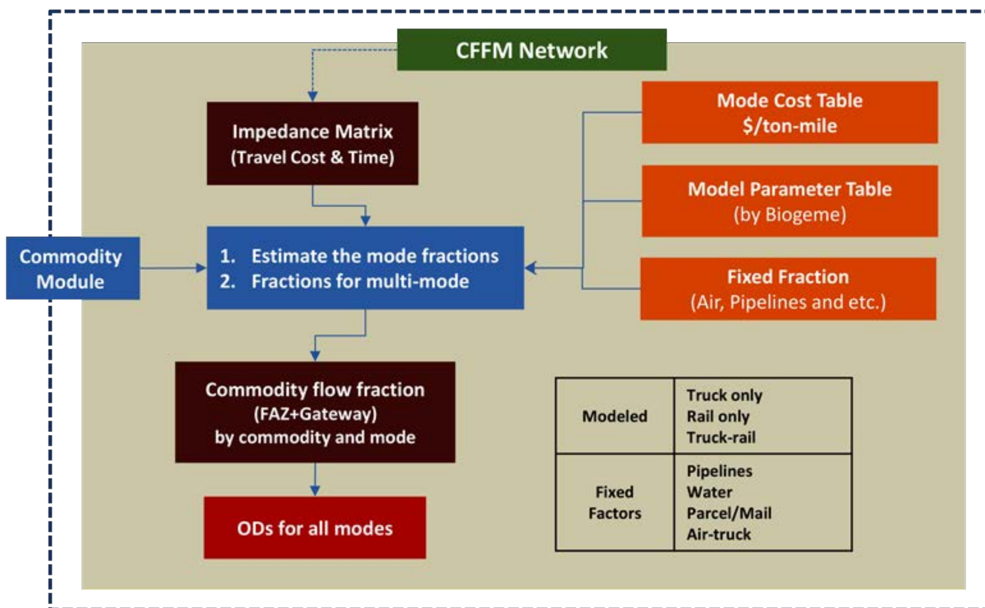

Figure 56. Flowchart. Mode split module framework.
(Source: Integrated CSTDM/CSFFM model.)

The incremental logit is formulated as:

$$s'_{ijcm} = \frac{s^0_{ijcm} e^{\left(\gamma'_{ijcm} - \gamma^0_{ijcm}\right)}}{\sum_n s^0_{ijcn} e^{\left(\gamma'_{ijcn} - \gamma^0_{ijcn}\right)}}$$

Figure 57. Equation. Incremental logit formulation.

Where $s_{ijcm}{}^{0}$ and $s_{ijcm}{}'$ are the base and adjusted mode shares, respectively, for O-D ij, commodity group (CG)c , and mode m. $\gamma_{(\gamma\_ijcm)}{}^{0}$ and $\gamma_{(\gamma\_ijcm)}{}'$ are the corresponding impedance or attractiveness measures.[14]

California is a vital multimodal international gateway with its air, sea, and land ports and has extensive infrastructure of rail terminals. Not surprisingly, a 25 percent of freight ton-miles movements have multiple mode segments (excluding pipeline flows). Hence, it is essential to incorporate transshipment activity within the CSFFM, where long haul multimodal trips are apportioned to travel through a TLN for mode transfer, instead of travelling by a single mode from origin to destination. The CSFFM Transshipment Module's design allows intermodal exchanges and transshipments to occur. The transshipment application deconstructs trips including multiple modes (truck-air or truck-rail) into individual mode segments based on congestion impacts on TLNs or intermodal terminals. It determines which TLNs are used for each intermodal commodity on the given transshipment network. The model assigns link-level modes to commodity flows, generates cyclic vehicles to transport the commodities, and allows for congestion at the links, the transshipment nodes, and at the centroids where loading and unloading can occur. An advanced inverse optimization model is used to calibrate the parameters of Freight Transshipment Assignment Problem (FTAP).[15]

The factors used in the conversion of tonnage flows to trucks flows in the CSFFM were primarily derived from the 2017 California Vehicle Inventory and Use Survey (CA-VIUS).[16] CA-VIUS provides estimates of payload factors by commodities by truck body type, distribution of different truck configurations for different distance ranges based on a survey sample of total of 11,118 fleets and 14,790 trucks. The average payloads by truck class is presented in table 41.

[14] NCHRP, 2008. NCHRP Report 606: Forecasting Statewide Freight Toolkit. Transportation Research Board, Washington, D.C.

[15] Goal Programming Approach to Allocate Freight Analysis Framework Mode Flow Data, Kyungsoo Jeong and Stephen Ritchie, Transportation Research Record: Journal of the Transportation Research Board, 2014.
Nonlinear inverse optimization for parameter estimation of commodity-vehicle-decoupled freight assignment, Joseph Y J Chow, Stephen Ritchie and Kyungsoo Jeong, Transportation Research Part E, Volume 67, July 2014, Pages 71-91.

[16] Findings from the California Vehicle Inventory and Use Survey, Mobashwir Khan, Anurag Komanduri, Kalin Pacheco, et al, 98th Annual Meeting of the Transportation Research Board, 2018.

Table 41. California Vehicle Inventory and Use Survey weighted average payloads by truck class.

Commodity Group	C1 10<GVWR <=14	C2 14<GVWR <=26	C3 26<GVWR <=33	C4 GVWR >33
1. Agricultural products	4,500	8,000	17,000	43,000
2. Wood and paper products	3,500	6,500	14,500	39,000
3. Crude petroleum	1,000	8,000		41,000
4. Fuel and oil products	4,500	6,500		46,500
5. Gravel/sand	3,500	7,000	16,000	30,500
6. Coal and metallic ore	4,500	8,000	13,000	40,500
7. Food, beverage, tobacco products	4,000	7,000	13,000	46,500
8. Manufactured products	4,000	7,500	17,000	48,000
9. Chemical, pharmaceutical	3,000	5,500	8,500	46,000
10. Nonmetal mineral products	4,000	6,500	14,000	37,500
11. Metal manufactured products	4,500	7,000	14,000	41,000
12. Waste material	4,000	7,500	19,000	44,000
13. Electronics	5,000	6,500	13,500	40,000
14. Transportation equipment	3,500	6,500	13,000	41,500
15. Logs and Lumber	3,500	7,500	16,000	42,500

(Source: Integrated CSTDM/CSFFM model.)

A simplified version FAF4 methodology was used to convert tonnages to a number of trucks (CSFFM has less commodity groups and less truck classes, relative to FAF). This is a three-step process:

1. O-Ds are allocated to one of the five distance bins such as less than 50 miles, 50-100 miles, 101-200 miles, 201-500 miles, 500 or mile.
2. For each distance bin, allocate tonnage to truck classes using truck allocation percentages based on five zone-to-zone distance ranges.
3. Convert freight tonnages for each truck class to their equivalent number of trucks using CA-VIUS respective payloads.

For every commodity, the tonnages between each pair of origin-destination (O-Ds) will be allocated to four class of trucks. The truck allocation distribution for each zone-to-zone distance bin is estimated based on CA-VIUS survey data and presented in table 42.

Table 42. Truck allocation factors for traffic analysis zones.

INDEX	MIN	MAX	10 to 14 GVWR	14 to26 GVWR	26 to 33 GVWR	GVWR >33
1	0	50	0.13	0.34	0.08	0.45
2	50	100	0.10	0.26	0.11	0.52
3	100	200	0.06	0.19	0.09	0.66
4	200	500	0.01	0.08	0.04	0.87
5	500	1000000	0.00	0.03	0.02	0.95

(Source: Integrated CSTDM/CSFFM model.)

The truck allocation factors for trips from/to TLNs have a different customized distribution, since at these facilities commodities are mostly transported in 20-, 40-, or 53-foot containers.

CSFFM is a comprehensive multimodal commodity based model. A detailed set of production and attraction variables are used to estimate the total commodity flows between 97 FAZs. However, many of these variables are not readily available at small TAZs such as variables from agriculture census, therefore it is not possible to replicate the same structure to the very refine zoning system used in passenger forecasting. Simpler equations are used to disaggregate flows between FAZs to respective TAZs to integrate the freight and passenger model.

For each commodity group the most representative North American Industry Classification System (NAICS) employment categories are selected and truck trips are proportionally distributed between TAZs. Table 43 shows these variables for each production and consumption equation.

Table 43. California Statewide Freight Forecasting Model freight analysis zones disaggregation variables.

Commodity Group	Production[1]	Attraction[1]
Agriculture products	EMP115	EMP311
Wood, printed products	EMP321,EMP322	EMP337,EMP42
Crude petroleum	EMP211	EMP324
Fuel and oil products	EMP324, EMP211	EMPTOT, POP
Gravel/sand and nonmetallic minerals	EMP212	EMPTOT, POP
Coal/metallic minerals	EMP212	EMP331, POP
Food, beverage, tobacco products	EMP115, EMP 311	EMP311, EMP722
Manufactured products	EMP31, EMP32	EMP42, POP
Chemical/pharmaceutical products	EMP325	EMP42, POP
Nonmetal mineral products	EMP331	EMPTOT
Metal manufactured products	EMP332, EMP333	EMPTOT, EMP333
Waste material	EMPTOT	EMP562
Electronics	EMP334, EMP335	EMPTOT, EMP42
Transportation equipment	EMP336	EMP441
Logs	EMP113	EMP321

[1] EMPxxx: Employment category xxx in NAICS data base.

Non-Freight Trip Table

The Non-Freight Truck Module was developed using: a sample of truck global positioning system (GPS) data produced mainly by commercial fleet management systems for commercial vehicles, detail truck body classification from Caltrans Truck Activity Monitoring System (TAMS), and a comprehensive set of classified truck counts. The disaggregated GPS data provides origin-destination flows for Heavy Duty (GVW>=26k lbs.) and Medium Duty (14<GVW<26k lbs.) Commercial Trucks between 5454 TAZs in CSTDM. The GPS sample dataset includes travel patterns for all types of truck trip purposes, including freight trips producing commodity flows from FAF, non-freight trips involving service trucks, utility trucks, construction and moving trucks, local delivery trucks, and others, and empty trucks' trips. This sample data was expanded to cover the complete Truck O-D table by using Origin-Destination Matrix Estimation (ODME) methodology, by assigning the sample O-D matrix to the model network, and by estimating an expansion factor so that the assigned volumes would match the available counts.

Once a complete O-D matrix is estimated, an O-D matrix of non-freight truck flows (including empties) was estimated by subtracting the disaggregated freight flow matrix (derived from FAF) from this expanded matrix.

Modal Network Assignment

The CSFFM 3.0 has two assignment options:

1. **Assignment of four truck classes in integrated multiclass user equilibrium process with CSTDM:** This method is used for statewide or regional transportation performance analysis such as volumes, VMTs, congestion, delay and travel time. However, given the complexity and scale of the model, it is not possible to track commodities by truck classes during this assignment process.

2. **Multi-commodity, multiclass CUBE Burrell Stochastic Assignment:** There will be a maximum of 60 commodity-truck classes (15 commodities times 4 truck classes) in total. It is possible that not all commodities utilize all truck classes. This is a truck-only assignment, but the resultant congested travel time from equilibrium assignment in the first assignment option (above) is used to initiate the Burrell Assignment. This method is used to trace commodities on the highway network and analysis, such as the percentage of each facility's use by different commodities (industries), VMT by industry, and critical first/last mile access for each industry.

FLORIDA'S DEPARTMENT OF TRANSPORTATION MODEL

Introduction

Florida has a large, complex multimodal freight transportation system. There are 15 deep-water seaports and the international trade moving through Florida's ports was valued at $56.9 billion in 2009. There are 2,786 miles of rail carrying 1.6 million carloads and 83 million tons of freight in

2008. Miami International Airport has the largest total international freight tonnage in the United States, given its proximity to Central and South America. There are 4,300 miles of highways in Florida that carry truck traffic around the State.

Key trends affecting freight mobility in Florida over the next 50 years include an innovation economy with emerging industries such as aerospace, clean energy, life sciences and creative industries, global markets, emerging megaregions, shifting development patterns, communication technologies, environmental stewardship and the changing role of the public and private sectors. Challenges for the transportation system arising from these trends include efficient and reliable connectivity as a global hub, congestion on intercity corridors, new logistics practices, sustainable environmental practices, and available funding.

Florida's FreightSIM model is a travel demand model component integrated into the Florida Statewide Model (FLSWM). Florida developed a trip based freight model for its FLSWM in the early 2000s. It developed FreightSIM to take advantage of the increasing understanding that freight chooses to move in complete supply chains consisting of multiple trips.

FreightSIM simulates the transport of freight between supplier and buyer businesses in the United States, focusing on movements that involve Florida. FreightSIM produces a list of commodity shipments by mode and converts those to daily vehicle trip tables that can be assigned to the national and statewide networks in the FLSWM along with trip tables from the passenger model.

General Information

Usage

FreightSIM is designed to be a policy sensitive freight model that can be used to:

- Inform infrastructure investment decisions.
- Evaluate congestion on Florida highways.
- Test the effectiveness of statewide transportation policies on mobility and the economy.
- Produce multimodal system performance measures for freight.
- Evaluate the impacts of private sector decisions on the State transportation system.
- Provide regional agencies with intercity freight travel for regional planning purpose.

Methodology

The approach used in the development of the FreightSIM Model uses supply chain and economic methods to explicitly model various aspects of freight decisionmaking behavior. In addition, this approach develops forecasts of freight mobility and competitiveness, providing decision makers with better information to make decisions about transportation investments and policies.

The approach used is based on a freight-forecasting framework developed for the Federal Highway Administration (FHWA) that includes both supply chain and tour-based methods at the national and regional scales, respectively. The supply chain methods at a national scale in this framework have been adapted to include additional level of detail in the State of Florida. There are plans to develop tour-based models at the regional scale and link these to the supply chain models in the future.

FreightSIM is comprised of several steps that simulate the transport of freight between each supplier and buyer business in the United States. Figure 58 shows these processes, with major input and output data identified. This modeling system includes selection of business locations, trading relationships between businesses, and the resulting commodity flows, distribution channel, shipment size, and mode and path choices for each shipment made annually:

- **Firm Synthesis.** Synthesizes all firms in the United States and a sample of international firms.
- **Supplier Firm Selection.** Selects supplier firms for each buyer firm by type.
- **Goods Demand.** Predicts the annual demand in tonnage for shipments of each commodity type between each firm in the United States.
- **Firm Allocation.** Allocates firms in each county to traffic analysis zones within the Florida region (including Georgia and Alabama).
- **Distribution Channels.** Predicts the level of complexity of the supply chain (e.g., whether it is shipped directly or whether it passes through one or more warehouses, intermodal centers, distribution centers, or consolidation centers).
- **Shipment Size and Frequency.** Estimates discrete shipments delivered from the supplier to the buyer.
- **Modes and Transfers.** Predicts four primary modes (road, rail, air, and waterway) and transfer locations for shipments with complex supply chains.
- **Trip Assignment.** Assigns shipments to specific warehouse, distribution, and consolidation centers if the shipment passes through one of those locations and predicts truck and auto volumes on the highway network.

The model incorporates a multimodal transportation network that provides supply side information to the model including costs for different paths by different modes (or combinations of modes) and which freight vehicle flows are assigned. While the model is focused on Florida, it encompasses freight flows between Florida and the rest of the world. Truck flows are assigned with passenger trip tables to highway networks to produce auto and truck volumes across the United States. While rail, air, and waterway flows could be assigned, the validation data are for rail, air, and waterway flows so that these are retained as trip tables.

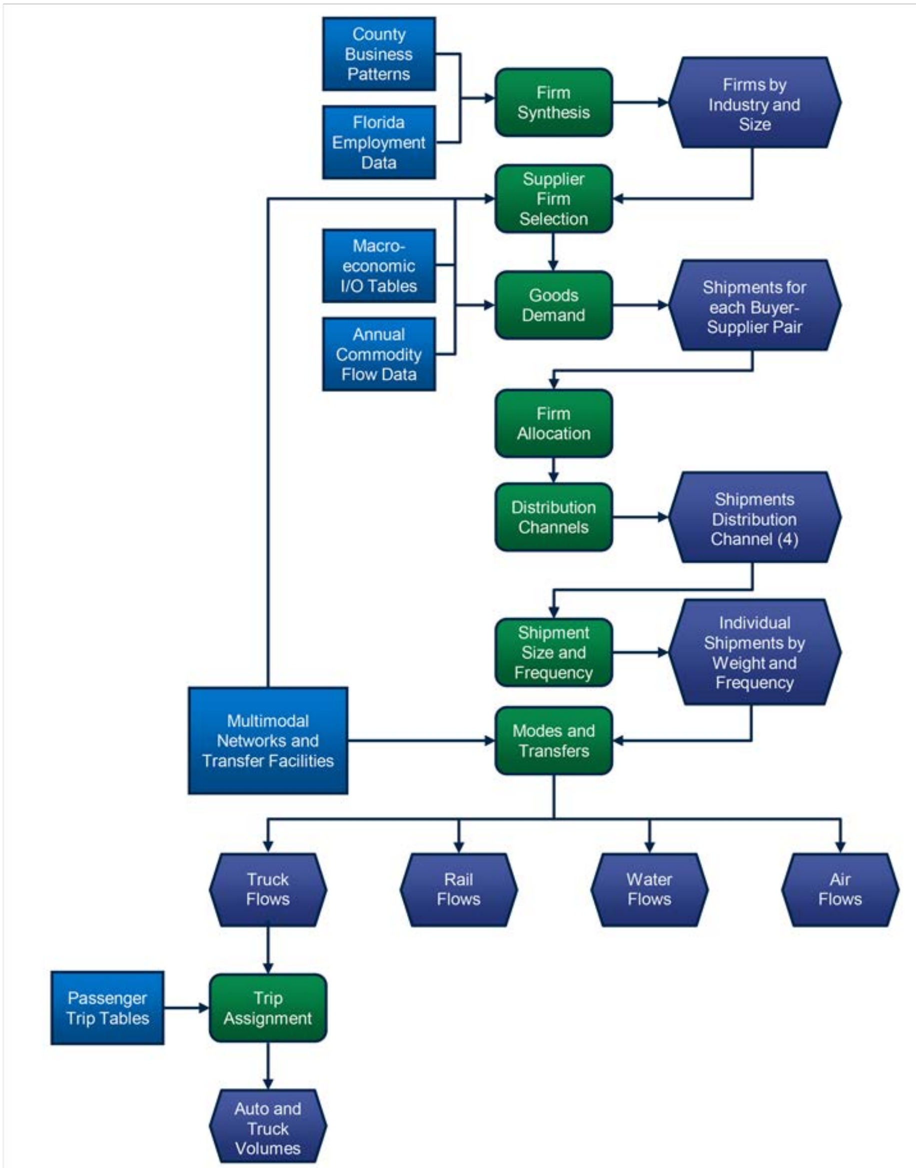

Figure 58. Flowchart. Freight supply-chain intermodal model process.
(Source: Florida's FreightSIM model.)

Coverage

Geography

There are three levels of spatial resolution used in FreightSIM:

1. **National and International Zones**. This is the broadest zone system, and it is comprised of domestic and international zones from the Freight Analysis Framework, Version 3 (FAF3). The FAF3 was developed by the FHWA to evaluate commodity flow data. These zones are used to represent all states except Florida, Georgia, and Alabama. There are eight international zones used for imports and exports. The firm synthesis model uses this zone system.

2. **Statewide County Level Zones.** An intermediate zone system comprised of counties in Florida, Georgia, Alabama, and FAF3 zones outside of these three States. This zone system is used in several model processes, including firm generation and supplier selection.
3. **Statewide Traffic Analysis Zones.** The model TAZ system consists of TAZs that are smaller in size within Florida and the parts of Georgia and Alabama with subcounty sized TAZs. This zone system is used during business location assignment, mode choice, and assignment.

Figure 59 shows the national and statewide zones used with the FAF3 data.

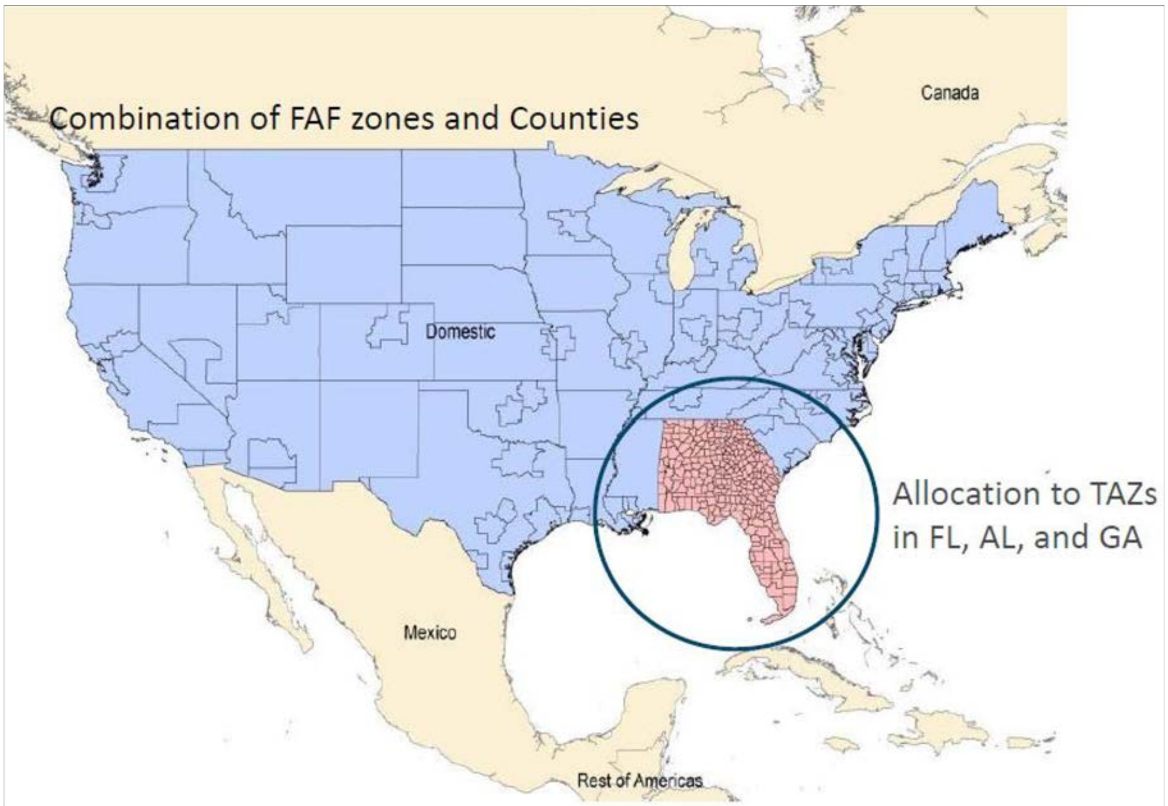

Figure 59. Florida FreightSIM zones.
(Source: Florida FreightSIM.)

The different systems are used for apportioning high-level commodity flows to individual shipper-receiver pairs and identifying the set of feasible transport paths for each shipper-receiver pair. The geographic detail within Florida, Alabama, and Georgia is TAZs, while outside those three states the geographic detail is defined by FAF3 zones. Chapter 3 provides figures of these zones.

Modes

Shipments transported between each buyer-supplier pair are developed for four primary modes, consisting of: road, rail, air, and water. Networks of all four modes for the United States are used.

Commodities

The commodity groups from the FAF3 are the basis for the commodity flow model. The FAF3 categorizes the freight into SCTG commodity classes and reports movements by seven modes (truck, rail, waterway, and air [includes truck-air], multiple modes and mail, pipeline, and other/unknown) for each origin and destination (FAF3 zones).

Forecast Details

Different data inputs were used for model development, both as main inputs or as additional, miscellaneous datasets. Table 44 lists a summary of the main inputs that are required for the model. This table lists each input and describes its source, the module(s) where it is applied, and a general description of the data.

Table 44. Data inputs.

Type of Input	Input	Source	Module	Description
Zone Systems	FAF3 Zone System	FHWA	Firm synthesis, supplier firm selection, goods demand	Large regions, such as Combined Statistical Areas (CSAs), or States
	County-Level Zone System	U.S. Census Bureau	Firm synthesis, supplier firm selection, goods demand	Counties within FL/GA/AL
	Traffic Analysis Zone Level System	Florida Department of Transportation (FDOT)	Firm allocation, modes and transfers, trip assignment	TAZs within FL, counties (within the GA/AL) and FAF3 zones (outside of FL/GA/AL)

Table 44. Data inputs (continuation).

Type of Input	Input	Source	Module	Description
Network Elements	Network links	FDOT, Oak Ridge National Laboratory (ORNL) and U.S. Army Corps of Engineers'	Modes and transfers, trip assignment	Highway (FDOT), rail (ORNL), and waterway network (U.S. Army Corps of Engineers') links
	Transport and logistics nodes (TLN)	FDOT, ORNL, BTS	Modes and transfers	Specific nodes within Florida; representative nodes outside of Florida
	Great Circle Distance (GCD)	ORNL	Supplier firm selection	Distance between all county-level O-D pairs in the U.S.
	GCD to foreign zones	Created by project team	Supplier firm selection	Distance between U.S. counties and foreign FAF3 zones
Economic Data	Input-Output Make and Use Tables	U.S. Bureau of Economic Analysis	Supplier firm selection, goods demand	Values of commodities exchanged between industries
	Industry to Commodity Correspondence	Freight Activity Microsimulation Estimator (FAME)	Firm synthesis, supplier selection, goods demand	List of SCTG commodities produced by each NAICS6 industry
	NAICS6 Industry to Input-Output Industry Correspondence	U.S. Bureau of Economic Analysis (2002)	Supplier firm selection, goods demand	Correspondences between detailed NAICS6 industries and aggregated NAICS Input-Output industries
Freight Flows	FAF3 Commodity Flows	FHWA	Supplier firm selection, goods demand, model validation	Commodity flows between FAF3 zones
	Commodity Flow Survey	FHWA	Model validation	

Table 44. Data inputs (continuation).

Type of Input	Input	Source	Module	Description
Employment Data	County Business Pattern (CBP) Data	U.S. Census (2010)	Firm synthesis, firm allocation, model validation	Employment by industry
	Infogroup data	FDOT	Firm synthesis, firm allocation, model validation	Business operating in Florida
Validation Data	Truck Counts	FDOT	Model validation	Medium and heavy truck counts
	Truck Trip Origins and Destinations	American Transportation Research Institute	Model validation	Sample of truck trips by county and TAZ origin-destination
	Weigh-in-Motion Data	FDOT	Model validation	Truck weight distribution
	Carload Waybill Data	USDOT via FDOT	Model validation	Complete restricted dataset of Carload Waybills
	T-100 Data	BTS	Model validation	Air freight segment and market data
	PIERS Data	FDOT	Model validation	Import/export shipment data by Port

Freight Trip Table

The initial element of the model synthesizes all firms in the United States, and a sample of international firms, to capture long-haul freight movements. Each firm has individual characteristics that identify the following:

- Where are they located?
- How large is the firm?
- What industry do they operate in?
- Which commodities do they consume?
- Which commodities do they produce?

The geography within the region of interest (in this case, Florida, Georgia, and Alabama) is divided into counties. The geography outside the region is defined by FAF3 zones. This model synthesizes firms by industry category and by size category to capture the primary drivers of commercial vehicle travel. Firm synthesis is controlled by regional, county, and State control totals.

Firms by size and type are allocated to analysis zones using available observed data sources on employment by type, consistent with the data used in the passenger travel demand forecasting model. These employment data were primarily from Infogroup data for Florida and CBP collected by the Census Bureau.

Input output data from the BEA were used to describe what each industry produces (makes) and consumes (uses). These relationships are known as make and use tables. When multiple commodities are made or used, then the data represents a proportional value.

The models for firm synthesis and business location were developed for Illinois at the Chicago Mesoscale Freight Model and were translated into the computer programming language R by the project team for the development of the FHWA Freight Forecasting Framework Project. The model for firm synthesis is a direct enumeration process of the firms based on the employment totals. Firms are enumerated by two attributes: 1) industry (NAICS); and 2) the employee size category for each geographic unit.

The supplier firm selection element pairs up buyers and suppliers among the firms that have been synthesized in the previous step based on the size of each firm, their industry, and the distance between them. The model for supplier firm selection is based on earlier freight modeling work for the Chicago Metropolitan Agency for Planning. For each buyer/consumer firm, a supplier is selected from the suppliers/makers dataset. The selection of a supplier does not mean the selection of an exact business, but that of a firm type (a combination of industry NAICS, commodity SCTG, and the geographic ID of a firm). The exact firm is determined after the next step of firm allocation (of each firm to a TAZ) is done.

Goods demand predicts the demand in tonnage for shipments of each commodity type by each firm in each industry. The demand is developed to represent the goods produced by each firm and the goods consumed by each firm (and household) in the United States.

The goods demand model relies primarily on the FAF3 freight flows and the buyer-supplier pairs estimated in the supplier firm selection model. The model also incorporates input-output tables to determine the allocations between industry types. The amount of commodity shipped on an annual basis between each pair of firms is apportioned based on the number of employees at the buyer and their industry so that observed commodity flows are matched.

Supply chain model components are described in the following subsections: firm locations, distribution channel, and shipment size and frequency.

Up to the firm location step, the geographic identifier for all zones has been the Statewide county-level zone (represented by counties for zones within Florida, Georgia, and Alabama and FAF3 zones for those outside). For the purpose of mode choice and simulation of freight traffic, the firms in the Florida modeling area are assigned to a higher resolution geographic ID, or TAZ. There are a few county zones that correspond to only one TAZ. The other counties correspond to more than one TAZ. TAZs are assigned to firms in these counties based on employment ranking by industry.

A dataset is prepared from employment data that contains the percentile ranking of each of 21 NAICS categories by TAZ based on employment numbers in each of those industries. Higher employment numbers implies a higher percentile rank. For industries in each of the 21 NAICS categories considered, candidate TAZs are identified based on firm size and the ranking of a particular NAICS in a TAZ. The probability of a TAZ getting assigned to a particular firm increases with the rank of the firm's NAICS in the TAZ and the number of employees in the firm. For example, if a firm belongs to the manufacturing industry and has a firm size greater than 5,000, then all TAZs that have manufacturing ranked ninth or tenth are candidates for the particular firm. Once candidate TAZs are assigned to each firm, one of the candidates is randomly selected as the firm's TAZ. Firms not in the Florida modeling area are assigned a TAZ number based on their statewide county-level zone number and combined with the Florida modeling area dataset to create a full firms database with TAZs attached.

The distribution channel model selects the channel for the shipment, a key element of the framework that represents an important business decision made by shippers. A distribution channel refers to the supply chain a shipment follows from the supplier to the consumer/buyer and it is critical to business freight related operations. The supplier firms may use their own transportation resources or send shipments to the buyer using third-party logistics firms. The distribution channel might affect the cost, shipment size, and frequency of shipments between a buyer-supplier firm pair.

In this framework, the transfer facilities are represented in the supply chain rather than including all establishments that goods move through as they travel from the producer to the consumer; this is because of limited data for these detailed supply chains. National supply chain data, when they become available, could improve this element. The distribution channel model uses discrete choice methods to identify the unique aspects of the supply chain.

An establishment survey was used to represent the elements of the supply chain, which contained data on whether the goods went through a consolidation center, a distribution center, and/or a warehouse. Other aspects of the supply chain were not possible with this dataset, and other datasets did not have the national coverage or details about the supply chain for this purpose. This survey was a small sample (570) of shipments across the United States and a diverse range of industry types. In this survey, there were 47 percent of shipments with no intermediate stops, 38 percent with one intermediate transfer location, and the remaining 15 percent of shipments with two or more stops. As expected, shorter trips tend to have fewer transfers.

For shipment size and frequency, the annual goods flow between buyer-supplier firm pairs are broken down into individual shipments. The shipment size (weight) and the corresponding number of shipments per year are determined. Shipment size affects the mode used to transport the shipment. This framework is not designed to optimize the shipments or identify the logistics of how shipments may be combined to make a truckload or rail delivery.

A multinomial logit (MNL) model is estimated for choice of shipment size. The Texas commercial vehicle survey dataset was used for estimating the discrete choice model due to its relatively high sample size. This dataset is not ideal for the shipment size model because the shipments represented in the dataset are likely to include many within an urban area. However, this dataset is most appropriate considering the sample sizes in other datasets.

Mode and transfer choice assigns a mode for shipments transported between each buyer-supplier pair. There are four primary modes (road, rail, air, and water) included in the mode choice model. Networks of all four modes (i.e., road, rail, water, and air) for the United States are used.

The modes and transfer locations on the shipment paths are determined based on the travel time, cost, characteristics of the shipment (e.g., bulk natural resources, finished goods), characteristics of the distribution channel (e.g., whether the shipment is routed via a warehouse, consolidation, or distribution center), and whether the shipment includes an intermodal transfer (e.g. truck-rail-truck). A mode and path (from a set of feasible modes and paths) is chosen, one that would have the least annual transport and logistics cost using a two-step process:

- First, a set of feasible paths between each O-D pair is enumerated.
- Second, a reasonable set of parameters is applied to the path skims to generate total annual transport and logistics costs for each combination of path and mode.

In calculating the total annual costs for each pair of seller and buyer, supply chain and inventory control costs are considered and incorporated to account for the inventory-associated costs.

Methods are used to predict the path and mode of long-haul movements of freight into, out of, within, and through Florida. The path includes identifying the location of intermodal transfer facilities, distribution centers, or warehouses where shipments are consolidated or de-consolidated. Detailed networks of road and rail for the United States were used, in addition to networks describing airport and port locations, domestic waterway connections, and finally great circle distances (GCDs) between airports and between ports and international destinations.

Total logistics costs that the buyer and supplier encounter is the sum of transport and inventory costs and can be itemized as shown below:

$$\text{Total Logistics Costs} = \text{Transport costs} + \text{Inventory costs}$$

Where:

$$\text{Inventory Costs} = \text{Ordering} + \text{Carrying} + \text{Damage} + \text{Inventory in-Transit} + \text{Safety Inventory}$$

- Ordering = Order preparation, order transmission, production setup if appropriate.
- Carrying = Cost of money, obsolescence, insurance, property taxes, and storage costs.
- Damage = Order lost or damaged.
- Inventory in-transit = Inventory between shipment origin and delivery location.
- Safety Inventory = Lost sales cost, backorder cost (Demand and Lead-time uncertainty).

This formulation models logistics decisions in a joint fashion by capturing transport and logistics costs in a single equation. This effectively reflects the real-world decisions of freight movers by accounting for different components of costs. These models for mode choice and intermodal transfers were based on the formulation developed by de Jong and Ben-Akiva (2007), shown in figure 60.

$$G_{mnql} = \beta_{0ql} + \overbrace{\beta_1 \times \left(\frac{Q}{q}\right)}^{\text{Ordering Cost}} + \overbrace{T_{mnql}}^{\text{Transport Cost}} \times \overbrace{\beta_2 \times j \times v \times Q}^{\text{Damage Cost}} + \overbrace{\beta_3 \times t_{mnl} \times v \times \frac{Q}{365}}^{\text{Inventory in-Transit Cost}} + \overbrace{(\beta_4 + \beta_5 \times v)\left(\frac{q}{2}\right)}^{\text{Carrying Cost}}$$

$$+ \underbrace{\beta_5 \times v \times a * \sqrt{(LT \times \sigma_Q^2) + (Q^2 \times \sigma_{LT}^2)}}_{\text{Safety Stock Cost}}$$

Figure 60. Equation. Estimate of the generalized logistics costs for freight movement. (Source: de Jong and Ben-Akiva (2007).)

The mode and transfer model is the final freight demand component in FreightSIM. This is the point in the model system where the standalone statewide model deviates from the complete integrated model system where truck trips are simulated using a truck touring model. While the ability to connect to a truck touring model is retained in FreightSIM, in the statewide model the focus (for trucks at least) is on vehicle flows on the major highway network as opposed to urban truck movements.

Therefore, the final parts of the model focus on grouping shipments by mode from the results of the mode and transfer model and aggregating them into zone to zone movements. In the case of shipments moved by truck, those shipment movements are converted to zone to zone truck trips that can be assigned to the highway network.

The trip table conversion component follows a conventional approach to converting shipment flows to truck trips. The steps followed are:

- **Separate full shipment routing from mode and transfer model in to separate zone to zone trips.** In this step, the shipments by mode combinations like truck-rail-truck are split into separate modal trips (e.g., truck and rail trips in the case of truck-rail-truck). This requires using the zone that the intermodal transfer(s) occur in as new trip origins and destinations for the modal trips. The output is a set of shipment trips from an origin TAZ to a destination, described with variables including mode and the shipment's characteristics such as commodity, weight, and value.

- **Convert shipments trip to vehicle trips by size.** Payload factors that are based on distance and SCTG commodity are applied to the shipments to identify the number of truck trips that are required to deliver the shipment.

- **Divide truck trips into vehicle classes.** The observed distribution of medium and heavy trucks in the truck counts is used to simulate a truck size for each truck trip.

- **Add empty truck trips.** An allowance is made for some return empty trips based on empty factors that vary by the SCTG commodity group. These are applied using simulation; if a trip is selected to have a return empty trip then this trip is added to the trip list as the reverse trips with zero weight and value and then origin and destination transposed.

- **Sampling from the annual trips to create a daily sample.** Up until this point, the trip list being manipulated is a representation of a full year's commodity movements and truck travel. A sample that represents an average day is created from the annual trip list. For annual frequency conversion to daily, a factor of 310 is used as recommended in NCFRP Report 8 https://www.nap.edu/login.php?action=guest&record_id=14445.

- For daily frequencies of more than one (i.e., 310 or more trips per year), the daily frequency is rounded and otherwise sampling is used to identify if the trip should be included in the daily sample.

- **Aggregate trips into trip tables.** The trip list (a database of individual trips, with one row per trip) is aggregated into a trip table, a simpler table with one row for each pair of TAZs and truck type, with the sum of the corresponding number of truck trips as the only data item. The model exports both the complete trip list as well as the trip table, which is at this point ready to be used in the Florida Statewide Model trip assignment along with all other vehicles.

Non-Freight Trip Table

Non-freight truck trip tables are generated by the Florida Statewide Model (FLSWM) as a part of the separate modeling procedure. The model produces non-freight trips for light (FHWA classes 2-3), medium (FHWA classes 5-7) and heavy (FHWA classes 8-12) commercial trucks.

Model Network Assignment

The assignment model includes the light, medium and heavy truck volumes for freight (FR) and commercial vehicles (CV) separately, reflected in the following six new volume sets:

- **FR_Med.** Medium freight trucks (FHWA classes 5-7, trucks carrying freight).
- **FR_Hvy.** Heavy freight trucks (FHWA classes 8-12, trucks carrying freight).
- **FT_Lte.** Light freight trucks (FHWA classes 2-3, auto/trucks carrying freight; note that FreighSIM does not generate freight carrying vehicles in this class.
- **CV_Med.** Medium commercial vehicles or non-freight trucks (FHWA classes 5-7).
- **CV_Hvy.** Heavy commercial vehicles or non-freight trucks (FHWA classes 8-12).
- **CV_Lte.** Light commercial vehicles or non-freight trucks (FHWA classes 2-3).

Note that the term "commercial vehicle" is used here to identify non-freight vehicles, such as utility trucks, fire trucks, service vehicles, etc. These commercial vehicles tend to be more prominent in metropolitan regions and tend to have shorter trip lengths; as a result, they are more important to validate within the regional truck models than in the statewide models, but are nonetheless an important reflection of total trucks in the system. The separation of these trucks is useful in the context of FreightSIM.

IOWA'S DEPARTMENT OF TRANSPORTATION IOWA STATEWIDE TRAFFIC ANALYSIS MODEL AND IOWA FREIGHT OPTIMIZATION MODEL

Introduction

Iowa's central geographic location and abundance of transportation options make it a major player in the global marketplace. The transport of goods and services is the backbone of the State's economy and investments in basic infrastructure components such as airports, highways, pipelines, railroads, and waterways secure and strengthen the economic vitality of the State.

General Information

This case study describes how the Iowa Statewide Traffic Analysis Model (iTRAM) and the Iowa Freight Optimization Model (iFROM) are operated iteratively by the Iowa Department of Transportation (DOT) in order to expand its freight forecasting capabilities.

- iFROM uses network data from iTRAM to provide impedances.
- The truck results from iFROM are input to iTRAM for highway assignment to analyze changes in highway traffic patterns.
- Additionally, iTRAM has a separate rail freight model to provide forecast on the rail system that is important to Iowa.

The results from both models provide useful freight forecasts for Iowa DOT. iFROM uses network data from iTRAM to provide the impedances. The results from iFROM are input to iTRAM for highway assignment to analyze changes in traffic patterns.

Usage

The Iowa DOT developed the iTRAM to assist in its planning efforts. The first generation of iTRAM focused on car and truck traffic on highways in Iowa and in the States surrounding Iowa. It was used to analyze many issues including: supplementing the rural foresting process; flood detour analysis; by-pass studies; and rest area studies. To assist in its freight planning efforts, freight enhancements were included during the development of Iowa DOT's second generation of iTRAM.

Methodology

The updated iTRAM model consists of three main parts, each comprised of multiple steps as shown in figure 61.

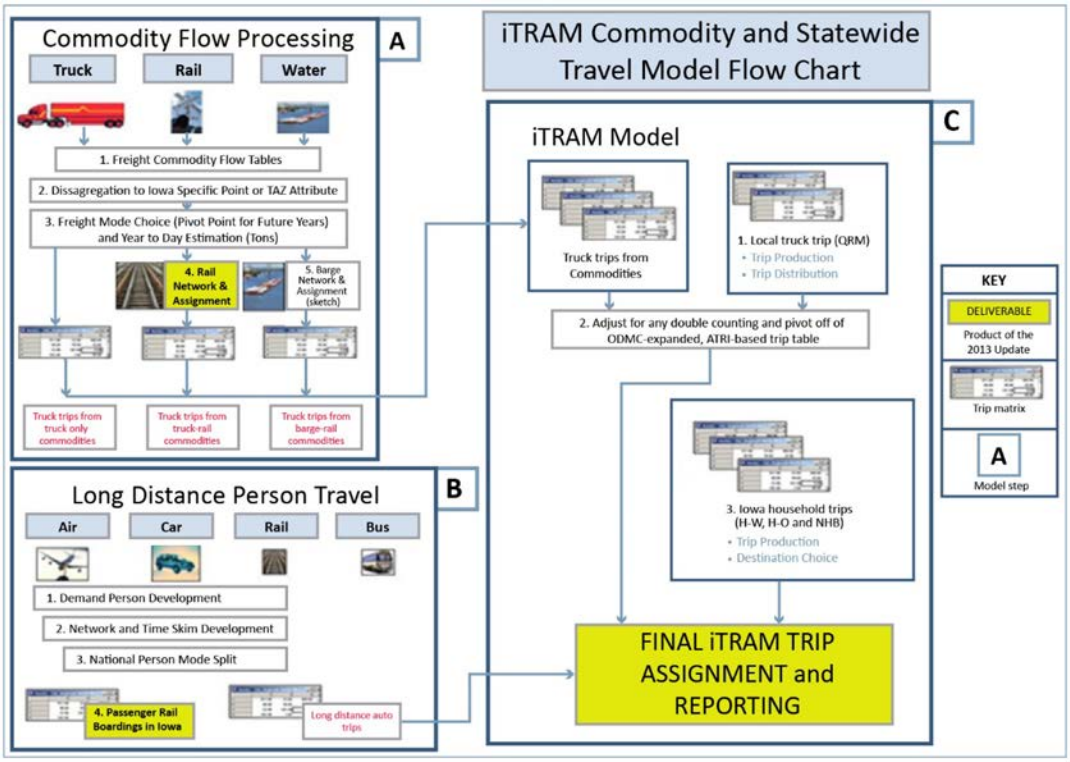

Figure 61. Flowchart. Processing steps in the second generation of Iowa Statewide Traffic Analysis Model.
(Source: Iowa Statewide Traffic Analysis Model (iTRAM).)

- First, the commodity flows by truck, rail and water are analyzed as shown in Box A. It should be noted that the flows by domestic water (barge) are only assigned at the sketch level and are not disused further. Iowa's barge network only needs to include freight flows on the Mississippi and Missouri Rivers bordering Iowa, and performs sketch assignments.

- In parallel, the long-distance person travel in the State is analyzed and the passenger model accounts for intercity travel by auto, air, rail and bus.

- Both feed into the iTRAM statewide model for passenger and freight. As shown in Box C of figure 61, the highway truck assignment combines and adjusts both commodity, freight, and other trucks to observed truck flows.

As currently constituted, iTRAM cannot report congested assignments for only trucks that carry freight. The rail assignment, which include the rail portion of rail-truck flows, is more advanced. While this freight enhancement provides the ability to forecast changes in rail route assignment, in response to among other things, rail track closures, it does not provide the ability to forecast changes in demand resulting from shifting demand among freight modes. Iowa DOT has a separate tool, the iFROM which optimizes usage among commodity supply chains.

iTRAM's Rail Freight Model provides the ability to address how rail bridge closures will reroute traffic within Iowa, or what rail tracks are used to transport specific commodities. iFROM can optimize commodity supply chains and address how new intermodal terminals or changes in cross dock trucking operations might impact flows within Iowa. Together these models provide the ability to comprehensively address larger freight planning issues.

The process that uses these speeds/impedances is disused as part of the assignment. Although individual railroads are limited to regional service, even if those regions are multi-State for the Class I Railroads, and cooperate by exchanging freight cars and equipment to provide national coverage. These exchanges occur at locations designated as interline connectors. These interline connectors can represent direct interchanges of rail equipment, or can represent the physical transfer of freight commodities between rail a terminal located at a distance. Interchanges that operate over capacity create bottlenecks in the system. Chicago an extreme example of the bottlenecks created by these transfers and is included in the Iowa National Rail network.

Track ownership and usage rights create display problems when summing commodity usage by railroad. The flows along sections of track should be assigned to those railroad tracks, but the usage of that track may be attributable to more than one railroad. The national rail assignment addresses this by including two networks, an assignable railroad and a "display" network. The assignment of commodity flows is to the assignable network, while the summing of flows for all track owners uses the "display" network.

iFROM focuses the capacity and performance of the networks. It separately estimates the level of service from the various networks in order to provide tables of the utilities between zones. iFROM forecasts changes in the optimal allocation of commodity flows by supply chain. These supply chains are reported by the mode representing the long haul component foot that supply chain. The demand tables that are output from iFROM are then input to iTRAM to determine the implications on network usage and performance. The truck flows that are part of truck- rail and truck-barge supply chains are extracted as legs of those supply chains.

Coverage

Geography

iTRAM's highway network covers only Iowa and its surrounding States. iTRAM's Rail Freight Model uses two separate networks: 1) a national network derived from the Oak Ridge National Laboratory's (ORNL) Center for Transportation Analysis Rail Network, and 2) an Iowa Centric Rail Network which includes additional rail links representing the Class III railroad links in Iowa that are not included in the national network. The national network includes county level centroids both in and outside Iowa. The Iowa Centric Rail Network in Iowa includes centroids that are counties outside of Iowa and active freight stations within Iowa. Figure 62 shows the base year rail network.

Figure 62. Map. Iowa centric rail network.
(Source: Development of Iowa statewide Freight Transportation Network Optimization Strategy, Final Report, September 2016.)

The attributes on the network links are from the iTRAM TransCAD network, which includes such information as:

- Height (overhead clearance).
- Gauge (e.g., Standard, Electric, Cog, or Narrow).
- Weight, standard for freight cars allowed in normal operations.
- Ownership and allowed usage of the rail links.

These attributes and the number and type of track (e.g., main line or minor branch), track usage (e.g., through, siding, spur, or yard transfer), and the signal system (e.g., automatic or manual) from the ORNL network, are used to determine the rail speed/time impedance.

Table 45. Rail impedance calculation.

Main Line Class		Speed by # of Tracks		Adjustment for Manual
MLC ID	Description	1 Track	2 or More Tracks	
A	Main	50	55	-5 MPH
B	Main	40	45	-5 MPH
C	Main	30	35	-5 MPH
G	Branch	25	30	-5 MPH
H	Branch	20	25	-5 MPH

(Source: Iowa DOT Rail Freight Network, 2014.)

iTRAM uses two rail networks for its assignment and analysis process: a national network and an Iowa Centric Rail Network. The zones in the iTRAM's national network are counties, both within and outside of Iowa. The zones in the Iowa Centric Rail Network are counties outside of Iowa and active freight stations within Iowa. The zones in iFROM are counties within the Iowa, 3 digit zip codes domestically outside Iowa, and countries or groups of countries for international demand.

Modes

iTRAM forecasts four modes of freight movement; truck, rail, water, and multimodal.

Commodities

iTRAM's disaggregation of the FAF retains the reporting of freight flows by the SCTG2 commodity in FAF. The Carload Waybill Survey, which is used as the table of demand for the Iowa Centric rail assignment in iTRAM, is to freight stations located within counties, within counties, and reports freight flows by the STCC commodities used in the carload waybill survey (CWS). To retain consistency between the demand expressed in these different commodity systems, of FAF for the National rail assignment and of CWS for the Iowa Centric rail assignment, iTRAM includes a correspondence table of the SCTG2 codes reported in FAF and the first two digits of the STCC commodities reported in the CWS.

iFROM groups the freight demand tables into Commodity Groups that are distinguished by the commodity; mode, truck, expressed as Truckload (TL) and Less Than Truck (LTL) loads, rail, water and multimodal; and by equipment type, expressed as dry; refrigerated, and tank, where these distinctions are made by SCTG2 commodity. The key industry clusters for Iowa's economic development, and the commodities needed to support those industries were identified. This resulted in the identification of 13 prioritized commodities at the SCTG2 level that are retained from the FAF and modeled individually in iFROM. Those commodities represent over 60 percent of the tonnage for Iowa as shown in table 46.

Table 46. Percent freight tonnages for rail, water and multimodal.

SCTG Code	Description	% of Total Domestic Freight Tonnage Rail, Water and Multimodal for Iowa
02	Cereal grains	32.80%
03	Other agriculture products	4.86%
04	Animal feed	7.29%
06	Milled grain products	1.16%
07	Other foodstuffs	5.10%
20	Basic chemicals	1.03%
24	Plastics/rubber	0.83%
26	Wood products	0.66%
31	Nonmetal mineral products	5.70%
34	Machinery	1.22%
35	Electronics	0.20%
36	Motorized vehicles	0.52%
38	Precision instruments	0.01%
Total		61.36%

(Source: Base year data from FHWA, Freight Analysis Framework 3.5.)

The remaining FAF SCTG2 commodities are grouped into three aggregated commodity groups: Mixed High Density Freight, Mixed Freight, and Mixed Energy and Chemical products. The individual and grouped commodities are then disaggregated by equipment types and modes to the final 24 commodity groups.

Forecast Details

Freight Trip Table

iTRAM disaggregates the FAF base and forecast year tables of commodity demand for its analysis. The domestic FAF regions are disaggregated to U.S. counties using relationships established by regression between commodities and industry employment. An example of such a regression is shown in figure 63 for origins of SCTG18 and the employment in industries that are the origins of SCTG18 flow.

Commodity-Employment Regressions: Fuel Oils (SCTG 18)

FAF Zones	Origins SCTG 18 tons_2007	2010 CBP_324	2010 CBP_4247
11	1640.4	670	750
12	90.1	385	353
19	2778.5	1190	1266
20	9604.8	510	1086
41	3643.8	281	800
42	288.4	60	121
49	326.3	230	449
50	5553.8	1500	1716
61	17419.5	6158	3185
62	809.7	259	723
63	675.2	99	429
64	12782.9	4539	1241
69	4317.8	1188	2468
81	6724.8	840	1009
89	1504.1	40	653
91	2651.5	31	266
92	8707.2	126	957
99	552.0	10	83
100	4175.0	820	157
111	16.8	0	10
121	3612.5	235	305
122	3211.2	610	1317

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.841548626
R Square	0.708204091
Adjusted R Square	0.703340825
Standard Error	4792.212598
Observations	123

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	6688560051	3344280026	145.6231704	8.03067E-33
Residual	120	2755836190	22965301.58		
Total	122	9444396241			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	19.14286837	563.5753268	0.033966832	0.972960034	-1096.697057	1134.982794	-1096.697057	1134.982794
X Variable 1	4.778012634	0.480519756	9.943426006	2.34034E-17	3.826616959	5.729408308	3.826616959	5.729408308
X Variable 2	1.258236917	0.534995987	2.351862344	0.020308667	0.198982095	2.317491739	0.198982095	2.317491739

NAICS	Definition	Normalized Weight
CBP_324	Petroleum and Coal Products Manufacturing	0.79
CBP_4247	Petroleum and Petroleum Products Merchant Wholesalers	0.21

Figure 63. Sample chart. Sample production regression fuel oils.
(Source: Iowa Statewide Traffic Analysis Model (iTRAM).)

The disaggregation of domestic flows is to counties based on those relationships that identify the employment in the industries that are associated with the commodity, and the share that a county had of the same FAF region's employment in those same industries. The source of the industry employment was the Census County Business Patterns, and Bureau of Economic Analysis employment for Iowa. The forecasts of employment in those same industries that were used to disaggregate forecasts of commodity flows were computed using Wood and Poole's forecasts of industry employment.

The foreign commodity flows were processed using two steps. The FAF region through which the foreign commodity moved was identified. Second, the county within that FAF region with the highest level of warehouse and transportation employment was selected as the portal. Those portal counties represented the domestic end of flows that begin or end in foreign countries. This produces three commodity flow tables of demand for iTRAM's national assignment: domestic, import (foreign flow origin), and export (foreign flow destination).

iTRAM's table of rail demand that is assigned to the Iowa Centric Rail Network was developed from the (confidential use) CWS available to Iowa. This survey of demand is already reported by U.S. counties and needs no further geographic disaggregation. Because the carload waybill was an input to the development of the FAF, the use of this table, is consistent with the national rail assignment.

The demand table used in iFROM is also created by disaggregating the FAF by a process that is similar to the one used in iTRAM. The intrastate flows within Iowa are disaggregated to counties. The Interstate flows are disaggregated to three-digit zip codes, which are aggregations of counties. The foreign flows are disaggregated to countries or groups of countries using Economic Development Research (EDR) group data. Imported commodities transported from a foreign zone to a U.S. Port zone as identified in the FAF are disaggregated from a FAF region containing a U.S. port to an Iowa node. Exported freight flows the reverse of that process. iTRAM and iFROM both disaggregate the FAF, although by different steps and to different geographies. The iTRAM's rail commodity demand table only uses flows from the FAF that are reported to use rail, while iFROM also disaggregates domestic water (barge) and truck flows. Because FAF is the ultimate source of both demand tables, these tables are assumed to be similar.

iTRAM does assign all rail demand, even if the demand only passes through Iowa, but does not have an origin and destination in Iowa. iFROM does not explicitly analyze flows that have both origins and destination outside of Iowa, but only travels on infrastructures in Iowa. iFROM cannot consider changes to these flows. The outputs of optimized supply chain demand that are imported to iTRAM for assignment. However, given Iowa's geographic location, and the truck, rail and water infrastructure serving Iowa, these "pass through" commodity flows are unlikely to change due to changes in demand or usage of supply chains to, from, or within Iowa.

Forecast changes in the economy will impact the disaggregation to the various geographic zones like counties. This adjustment will affect all counties or three-digit zip codes in that are within a FAF region, and is not limited to only where the economy has changed. It does not disaggregate just the difference between the FAF forecast and the FAF base year flows, using only changes in the industry employment. Additionally, locational changes to the economy below the county level cannot be considered. Neither iTRAM or iFROM compute freight flows by using trip generation or trip distribution. Rather they use the FAF as an acquired commodity database. Because the FAF is a linked, supply chain, shipper database, iTRAM must process the flows if intermediate stops along a supply chain are not identified such as intermodal terminals or other TLNs. It cannot reflect changes to the trading partners, such as freight distribution that is affected by those changes in the economy. iFROM is itself a supply chain optimization model where these stops will be an output of iFROM.

Because iTRAM's Rail Freight Model only considers the demand as disaggregated from the FAF using rail, it cannot forecast modal diversions. It can be considered an acquired commodity model, as discussed in chapter 8. iFROM can be considered to be the choice component of a Supply Chain model as discussed in chapter 10. Forecasts flows by all trucks, not differentiating between freight and non-freight truck. It adjusts the total truck assignment using the disaggregated FAF truck assignment to total truck flows. Iowa DOT retains and assigns the rail freight flows from iTRAM FAF disaggregation because of the importance of rail to Iowa. iFROM forecast changes in usage and performance by freight trucks. Those changes to truck flows (as truck drayage movements in multiple mode supply chains) are imported for assignment by TRAM.

The supply chain optimization in iFROM uses tables of the utilities of the supply chains that are defined by the mode used for the line haul. Transloading costs within the supply chain include not only modal transfers, but also cross dock operations where short distance trucking flows are transferred with line haul trucking flows within each supply chain. The utility tables for supply chains between zones consider network capacity, network resiliency, network reliability, and network access. The optimization routine considers those tables of supply chain utilities, the base table of multi-supply chain demand, in order to optimize the flows between zones by the available supply chains. The tables of changes in demand are input into iTRAM for assignment.

Non-Freight Trip Table

Non-freight trucks generated by iTRAM are considered local trucks and combined with commodity trucks to generate the universe of trucks. Both sets of trucks are adjusted to avoid double counting and pivot off an ODME-expanded American Transportation Research Institute (ATRI)-based trips table.

Model Network Assignment

Modal flow results from iFROM are input to iTRAM for network assignment. Because iTRAM and iFROM use different commodity groupings, only the aggregate impacts of commodity flows can be analyzed. Commodity truck flows can be assigned by the highway using the congested highway times from a highway iTRAM assignment. Because these flows are in tonnages, they can use the congested times that result from all vehicle assignments, including all trucks, for reporting purposes, but they cannot change those congested times. Changes in congested times would require assigning the commodity truck flows not as annual tons, but as truck vehicles for the time period used in iTRAM's highway assignment, and removing commodity freight trucks from the total trucks that are assigned in iTRAM's highway assignment.

The rail flows are assigned to the rail network using an all-or-nothing assignment. Other assignment procedures were tested but did not substantially change the results. In any event the rail capacities used are assumed to be average capacities over all railroads, and are not changed to reflect the actual business decisions of individual railroads.

The outputs from iFROM are also averages and do not reflect Time of Day (TOD) considerations. Neither the National or Iowa Centric Rail assignments in iTRAM reflect TOD assignments.

Individually iTRAM and iFROM are designed to provide comprehensive forecasts of freight forecasts, iFROM lacks the assignment capabilities. iTRAM lacks the ability to forecast changes in freight mode choice. By operating the models together, Iowa DOT has expanded its freight forecasting capabilities. While iTRAM combines both freight and non-freight trucks prior to highway assignment, iTRAM can analyze freight commodity changes that affect the freight rail assignment. The disaggregate flows from FAF used by iTRAM cannot be sensitive to changes in the Iowa economy or to changes in the transportation project, polices and program that might affect that demand. iFROM starts with assumptions of network attributes, that cannot reflect changes that result from new projects, policies, or programs analyzed in iTRAM. The combined interactive use of both programs addresses some of the shortcomings of each model and provides more sophisticated freight forecasts for Iowa DOT.

Both iTRAM and iFROM disaggregate commodity flows from FAF3, with a base year of 2007 and an ultimate forecast year of 2040. A refresh to iFROM is underway that will use the latest version of the FAF.

MARICOPA ASSOCIATION OF GOVERNMENTS MODEL

Introduction

Arizona has defined the Sun Corridor megaregion as covering portions of five counties that include the Maricopa Association of Governments (MAG) and Pima Association of Governments (PAG) regions, and is home to 8 out of 10 Arizonans.

The corridor begins in Santa Cruz County at the southern border of the City of Nogales, which is one of the busiest freight ports along the U.S.-Mexico border, and is a major gateway for fresh produce and manufactured goods. The corridor continues north along I-19 to Tucson and then west along I-10 to the Phoenix-Mesa metropolitan area, and ends in the City of Prescott at the north end. Driven by activity in the corridor, Arizona is expected to experience growth more than two times the national rate of growth between 2015 and 2050. The 2010 Census showed that the region ranks 10th among the largest U.S. metropolitan markets by population.

The importance of freight modeling and regional truck movement forecasts has long been recognized by Arizona DOT (ADOT) and MAG. MAG began researching and maintaining truck models more than two decades ago. The agency's commitment to improving freight modeling and taking the next steps in adopting behavior-based freight modeling reflects the following:

- First and foremost, freight movement and truck movement forecasting are critical for DOT and MPO business processes, such as air quality conformity analysis, development of regional and State transportation plans, and planning work on regional transportation projects.

- Second, the importance of freight has grown substantially during the past few years as a result of heightened attention to regional and statewide economic issues. The recent economic recession severely impacted Arizona and the MAG region in particular; freight is seen as one of the key transportation elements on the way to economic recovery.

General Information

The MAG has a tradition of advancing the understanding of travel demand forecasting and received Strategic Highway Research Program 2 (SHRP2) funding to develop the behavioral based freight model described in this case study.

Usage

The model has served as guidance for MAG updates and regular travel demand forecasting models. It has also been used as a standalone process to research and evaluate the impacts of various development scenarios.

Methodology

The MAG Next Generation Freight Demand Model is a behavioral-based freight model covering the majority of the freight and truck movement in the State of Arizona. The Maricopa Association of Governments (MAG), Arizona Department of Transportation (ADOT) and Pima Association of Governments (PAG) jointly developed a successful proof of concept proposal for the Strategic Highway Research Program 2 (SHRP 2) C20 Implementation and Technical Assistance Program (IAP) Grant. This led to the development of an operational mega-regional multimodal agent-based behavioral freight model based on the guidelines identified in the SHRP 2 C20 findings. The model was developed in accordance with the agencies' travel forecasting and planning needs.

The main project objectives were identified as follows:

- Improve and expand the knowledge base.
- Develop modeling methods to reflect actual supply chain management practices.
- Develop modeling methods based on sound economic principles.
- Maximize use of freight tools by public sector for planning and programming.
- Improve availability and visibility of data between public and private sectors.

The primary end product was a state-of-the-art multicomponent model which forecasts firm evolution, supply chain movement, and truck travel in the form of tours.

Figure 64 show the framework of the MAG model.

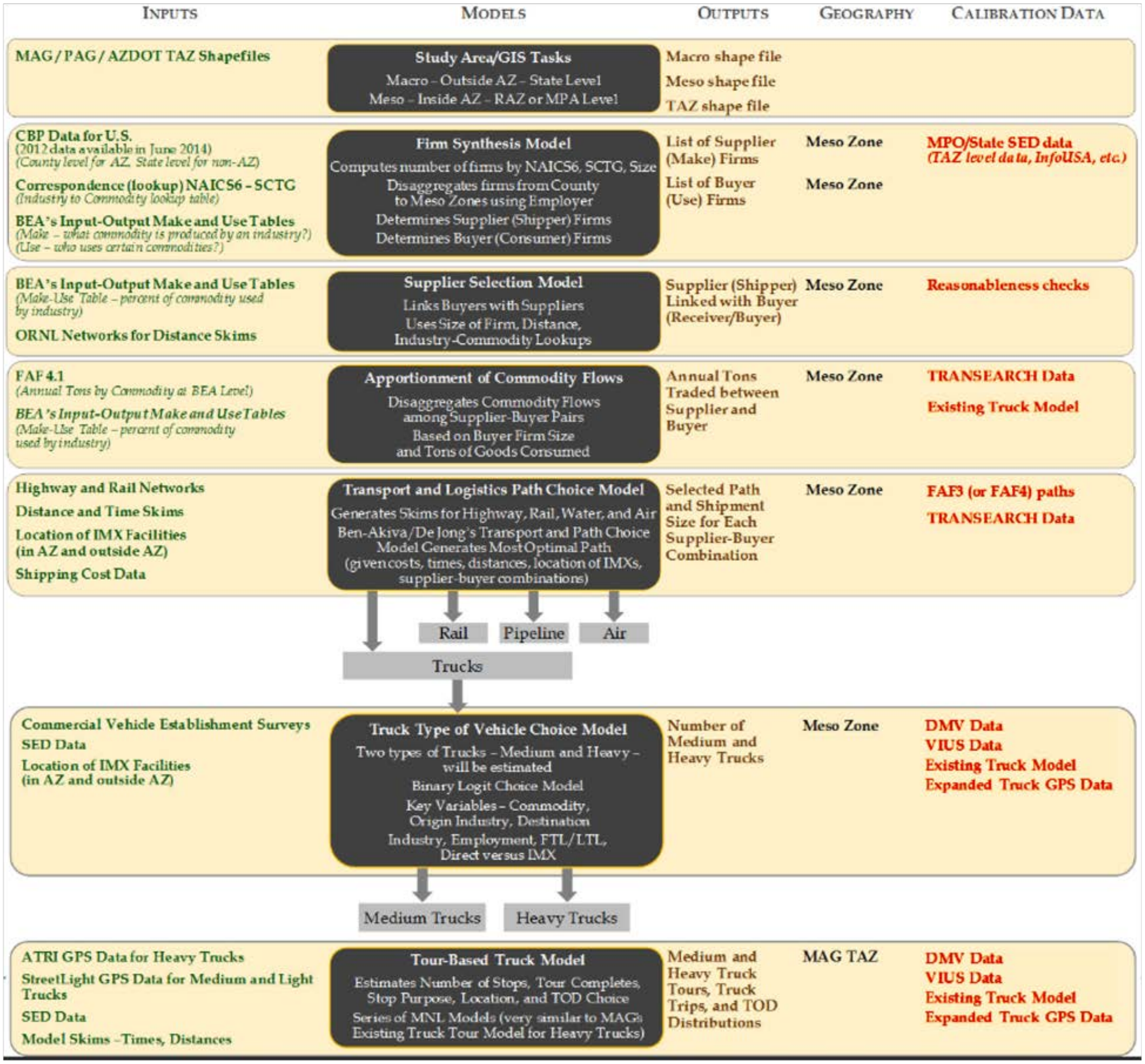

Figure 64. Chart. MAG Behavioral Based Model Framework.
(Source: Travel Model Improvement Program (TIMP) Webinar Series, November 15, 2017.
Presentation 1: MAG Behavioral Freight Model.)

The firm evolution model was the first of its kind implemented in the U.S. within a behavioral freight transportation model. Instead of producing aggregate estimates of a synthetic population of firms, this method predicts a disaggregate set by advancing from the base year to the future year and predicts the location, magnitude, and size of firms in the study region.

The agent-based supply chain and freight transport model uses disaggregate behavior-based logistics and transportation choice models to simulate commodity flows at firm level. The output of the model is records of shipments with their main characteristics including supplier, buyer, commodity type, total annual flow, mode choice, shipment size, rail yard used for trans-shipment (for rail shipments), and external highway station (for external truck shipments).

The truck tour model develops truck trip chains by industry sector by truck type. The tour-based model generates the number of stops by industry sector, number of stops on a tour, stop purposes, and the location and time of day of stops. Supply chain outputs are then converted to truck tours and integrated with the Truck Tour model output.

Coverage

Geography

Each modeling component is applied and produces outputs at different geographic levels—macro, meso, and micro. The exact definitions of these are subject to change based on the objectives and desires of MAG's planning needs. The MAG model zone system is shown in figure 65.

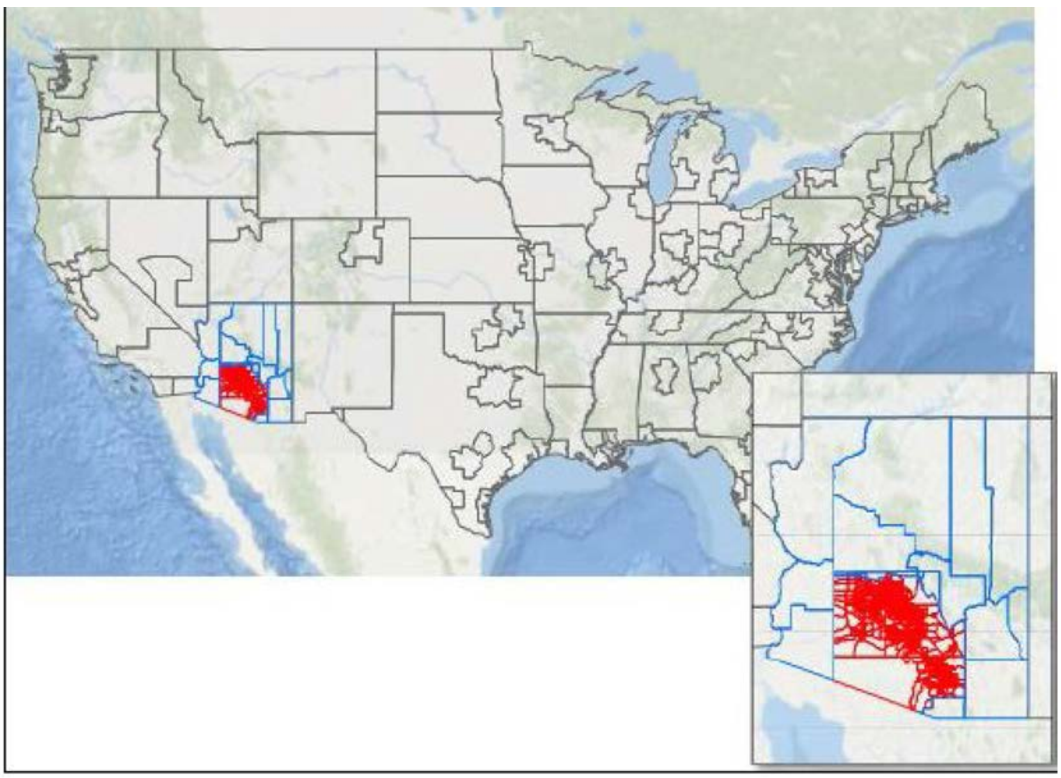

Figure 65. Map. Maricopa Association of Governments Model Zone system. (Source: MAG Next Generation Freight Demand Model.)

Modes

A nested logit model is estimated for freight mode and shipment size choice. Four modes of transportation, including truck, rail, air and parcel, such as U.S. Postal Service or UPS, are included in the model.

Commodities

TRANSEARCH combines primary shipment data obtained from many of the Nation's largest rail and truck freight carriers with information from public, commercial, and proprietary sources to generate a base year estimate of freight flows at the county level. Once the base year is completed, a separate model is used to produce a 30-year forecast of freight flows. TRANSEARCH database was purchased by MAG with a base year of 2013. It contains freight flows to, from, within, and through the study area.

The FAF integrates data from a variety of sources to create a comprehensive picture of freight movement among States and major metropolitan areas by all modes of transportation. With data from the 2012 Commodity Flow Survey (CFS) and additional sources, FAF Version 4.1 (FAF4.1) provides estimates for tonnage and value, by commodity type, mode, origin, and destination for 2015, the most recent year, and forecasts through 2045. 2015 base year internal-external, external-to-internal and internal-to-internal flows were extracted for the mega-region by the type of transported goods using Standard Classification of Transported Goods two-digit level (SCTG2) categories.

StreetLight Commercial Light and Medium Duty Trips' GPS data was utilized for the development of the light and medium truck tour models. The data contains the trip points for all light and medium duty commercial vehicle trips that started or ended in the region in April of 2015. The data was processed to produce stops and assigned stop purposes based on nearest land use or establishments as well as crosswalk tables between land use and stop purpose and between establishment NAICS code and stop purposes. Similarly to ATRI data processing, a stop table, a TAZ-to-TAZ trip matrix and a stop purpose-to-stop purpose trip matrix were produced for the model estimation.

Forecast Details

Freight Trip Table

The firm synthesis model predicts the location, magnitude, and size of firms in the study region. This model uses the National Establishment Time Series (NETS) database as a seed table. A series of econometric models are estimated to simulate the firm events that consider determinants such as firm internal attributes (size, age, and growth) and external attributes (market area characteristics, transportation costs, agglomeration economies). The businesses was classified by sixteen different two-digit NAICS groups.

The basic concept of a firm synthesizer model is to capture the evolution of firm population in time and space. It involves modeling a series of events related to firm births, deaths, and migration as depicted in figure 66.

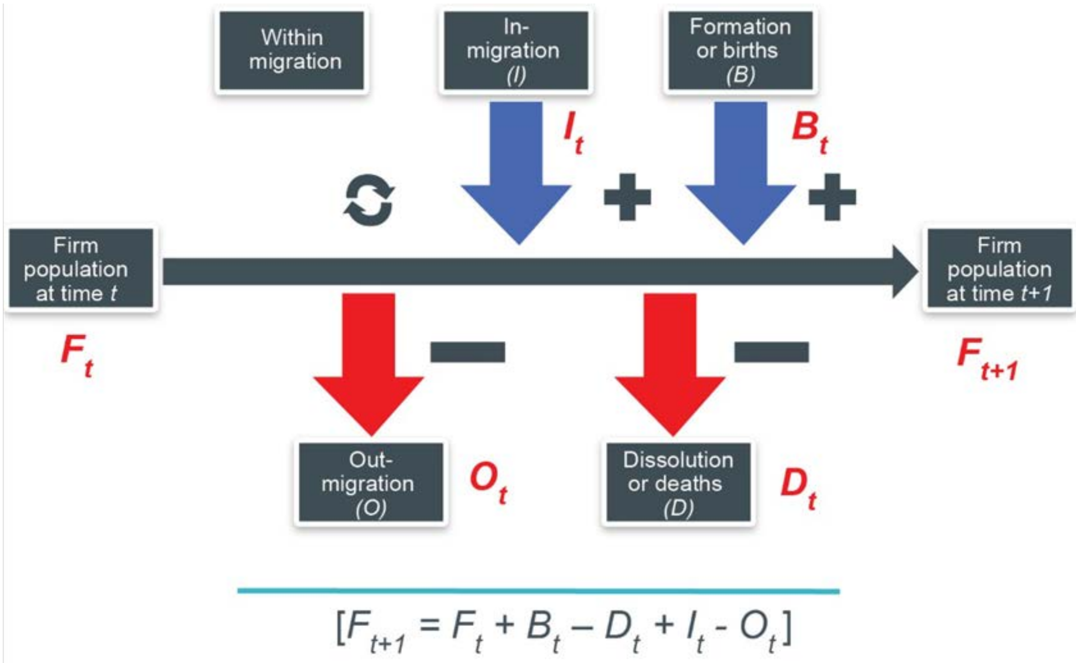

Figure 66. Diagram. Overview of firm evolution.
(Source: MAG Next Generation Freight Demand Model.)

- Birth of a firm is defined as the beginning (or first) year in which the business establishment was recorded in the NETS database for the MAG and PAG study area.
- Relocation is defined as change in address (or physical location) from one location to another.
- Firm death is defined as the last year in which the firm and its internal attributes were recorded in the panel from 1990 to 2012.

To analyze these firm dynamics related to birth, death, mobility, and growth, MAG uses a series of regression models to predict the probability of observing each of the firm's event. All the model estimation results are based from the NETS observed for years 2007 to 2011.

To capture the firm behavioral dynamics related to dissolution and relocation, a binary probit panel regression model was used to predict the probability of a firm being dissolved (or closed) or relocating from location *l* at time *t*. The model formulation for these events is illustrated in the equation in figure 67.

$$y_{it}^{e*} = \alpha' f_{it} + \beta' s_{it} + \gamma' z_{it} + \varepsilon_{it}$$

Figure 67. Equation. Firm behavioral dynamics equation.

Where:

y_{it}^{e*}—is the latent measure of observing an event *e*, in this case *e* takes the events of dissolution (or closure) and relocation, respectively.

f_{it}—is a vector of explanatory variables describing a firm's internal attributes *i* as related to employment, age and dummy variable of subsidiary and change in employment for time *t*.

s_{it}—is a vector of dummy variables indicating if the firm *i* is of a specific industry type as defined by the two-digit NAICS code as observed for time *t*.

z_{it}—is a vector of explanatory variables describing firm's *i* external attributes related to zonal level information of employment by two-digit NAICS and student enrollment numbers as observed for time *t*.

ε_{it}—random error term assumed to have a standard logistic distribution.

α, β, γ—vector of parameters estimated using the maximum likelihood method.

Employment size is used as a proxy to understand the trajectory of firm growth in the region. For this purpose, log-linear model specification to estimate employment size of the firm *i* for time *t* is illustrated as in figure 68.

$$\log(e_{it}) = \alpha' \log\left(e_{i,t-1}\right) + \beta' f_{it} + {}' s_{it} + \theta' z_{it} + \varepsilon_{it}$$

Figure 68. Equation. Employment size equation.

Where:

e_{it}—is the employment size (or number of employees) of the firm *i* for time period *t* and $e_{i,t-1}$ is the employment size of the firm *i* observed for time period *t-1*.

f_{it}—is a vector of explanatory variables describing the firm's internal attributes *i* as related to age and dummy variable of subsidiary for time *t*.

s_{it}—is a vector of dummy variables indicating if the firm *i* is of a specific industry type as defined by the two-digit NAICS code as observed for time *t*.

z_{it}—is a vector of explanatory variables describing the firm's *i* external attributes related to zonal level information of employment by two-digit NAICS and student enrollment numbers as observed for time *t*.

ε_{it}—random error term assumed to be normal distributed.

α, β, γ, θ—vector of parameters estimated using the ordinary least squares (OLS) technique.

Location choice is a long-term decision for newborn and migrating firms in the region and is modeled as a multinomial logit model. Given the previous location, with traffic analysis zones (TAZs) as choice alternatives *i,* for each firm *n,* this utility U_{in} for each alternative *i=1, 2,…, j* for an individual firm *n* is given by the function form as shown in figure 69.

$$U_{in} = V_{in} + \varepsilon_{in} = X_n A_{in} \beta_i + A_{in} \alpha_i + \varepsilon_{in}$$

Figure 69. Equation. Location decision utility function.

Where the systematic part $V_{in} = X_n A_{in} \beta_i + A_{in} \alpha_i$ accounts *for* location choice attributes A_i and an interaction between location and firm characteristics X_n, the coefficients α and β are estimated using maximum likelihood estimation techniques. The variables included in the specified model are attributes of location choices (or TAZs) A_i such as employment by NAICS industry type, population density and miles of freeways, arterials and collector roads. A selection of these location attributes also are interacted with individual firm characteristics $X_n A_i$ to capture observed sources of heterogeneity across firms for their response to location attributes.

The simulated results were validated with observed firm demographic trends along with zonal-level employment estimated using various goodness-of-fit measures. For instance, using a 20 percent validation sample, the firm synthesizer accurately projected firm events of birth, death, and relocation from 2007 to 2012. In addition, total zonal employment predicted in the region also closely resembles the observed trend, thereby also capturing the observed spatial distribution of employment in the megaregion.

The agent-based supply chain and freight transport model uses disaggregate behavior-based logistics and transportation choice models to simulate commodity flows at firm level. The model considers firms or business establishments as individual decision-making agents in the freight transportation system. It assumes that logistics and supply chain decisions are made by these agents and replicates their decision making behavior in the freight market. These logistics decisions include supplier selection, mode choice, and shipment size configuration.

The framework comprises two main modeling components (i) supplier selection model and evaluation of commodity flows and (ii) transport, mode, and path choice model.

The supplier selection and evaluation of commodity flows consists of two main steps. The first step is the freight generation process in which total annual commodity productions and consumptions are determined at firm level. The national and regional economic activity data and socioeconomic factors are used in a systematic procedure to estimate the commodity input-output rates per employee by industry class. This step generates a list buyer and supplier firms with the type and annual amount of commodity purchased or supplied. The supplier and buyer agents then enter the second step in which business partnerships are evaluated and business to business supply chains are formed between agents. The results of this model determine total annual commodity that is traded between each pair of supplier-buyer firms.

Once the supply chains are formed in the supplier selection and evaluation of commodity flows model, the total annual commodity flows between firms are used as input to the transport, mode, and path choice model in which logistics choices of mode and shipment size are analyzed for the commodity flows to, from, and within the Arizona Sun Corridor Megaregion. The nested logit structure is utilized to jointly model mode and shipment size choice. Four modes of transportation, including truck, rail, air and parcel (such as U.S. Postal Service, UPS, and other couriers) are included in the model. The continuous weight variable is classified into four categories of shipment sizes and are included in the model structure. The model is highly disaggregated and developed using the first generation of Commodity Flow Survey Public Use Microdata (CFS PUM). The model converts commodity flows into shipments between supplier and buyer. The output of the model is records of shipments with their main characteristics including supplier, buyer, commodity type, total annual flow, mode choice, shipment size, rail yard used for trans-shipment (for rail shipments) and external highway station (for external truck shipments).

The calibration of the model included calibration of the supplier selection model and calibration of the mode choice model. FAF4.1 data is the main data source for calibration of both models. FAF4.1 commodity flow patterns to, from, and within the MAG/PAG region were used for calibration of the supplier selection model and the modal split in the FAF 4.1 data was used for calibration of the mode choice model.

Non-Freight Trip Tables

The truck tour model develops truck trip chains by industry sector by truck type. These truck trip chains are then grouped into the major linkages based on land that the trucks make stops at; and the probability of making another stop based on the number of previous stops. The tour-based model generates the number of stops by industry sector, number of stops on a tour, stop purposes, and the location and time of day stops. The model used 2014 ATRI truck GPS data.

Truck tours are modeled through a sequence of models as shown in figure 70. These models include predicting tour generation at the zonal level by tour purpose (i.e., starting land use type), the number of stops for each tour, the purpose of those stops, the location of stops, and the time of day for stops. Separate models were developed for light, medium, and heavy trucks.

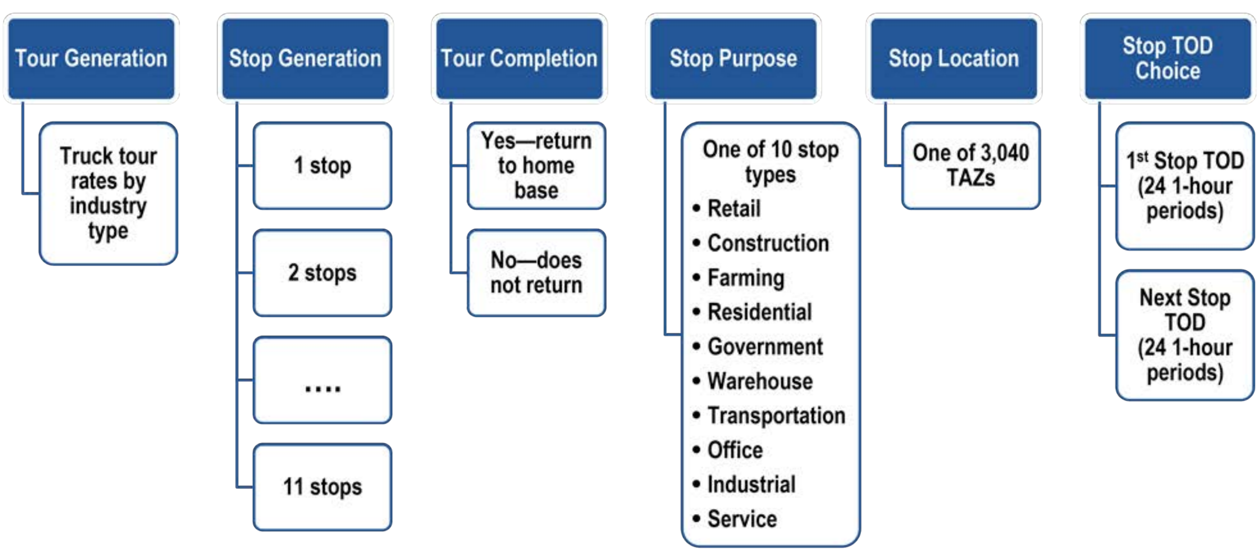

Figure 70. Chart. Tour-based truck model.
(Source: MAG Next Generation Freight Demand Model.)

The processed StreetLight truck GPS data was the basis for developing the estimation dataset for both light and medium trucks. The ATRI truck GPS database was used to develop heavy truck tour-based models. Using a combination of existing truck trip rates, tour completion percentage and average stops per tour, the tour rates were computed by tour purpose and then multiplied by the employment variable for each tour purpose to produce number of tours. A multinomial logit model was utilized to model the number of stops on each tour followed by a binomial logit model to determine if the truck returned to its origin location or not. Next, an multinomial logit (MNL) model predicts the purpose of the stops in sequence, that is, from the first stop to the last stop. The stop location choice model predicts the location (i.e., TAZ) of each stop simulated for the tour, and is similar in design to a destination choice model employed for distributing passenger trips. The stop time-of-day choice model predicts the time period of each stop on a tour. Two separate models were estimated for time-of-day choice. The first is used for the departure time of a tour's first trip, and the second is used for subsequent trips.

The individual model outputs also were compared against the truck GPS survey data to assess the model performance. These comparisons indicate that the model components are predicting closely to the observed data.

Model Network Assignment

The Supply Chain model outputs the supply chains of cargo that are used to transport freight to, from and within the combined MAG/PAG regions. These supply chains include cargo that is moved by truck. The Truck Tour model outputs truck trip chains by industry sector by truck type. The outputs from these models are used to create truck trip tables that can be assigned by the MAG/PAG model.

To covert supply chain outputs to truck tours and to integrate those truck tours with the Truck Tour model output, four types of truck tours were developed and then mapped to purposes within the truck tour model. The four types are:

- **Type 1 (freight cargo):** These are truck tours that are included within the Supply Chain model outputs. They are formed at the Transport Logistics Nodes (TLN) with the region that are an intermediate stop along a supply chain (For example, a TLN can be an intermodal rail terminal).
- **Type 2 (some non-freight cargo):** In the Supply Chain model, buyers of cargo include wholesalers, a NAICS 42 industry. However, that wholesalers only "buys" the cargo to have stock that can then be delivered locally, in tours that are considered as non-freight truck tours.
- **Type 3 (freight cargo)**: These are the truck tours that are outputs from the Supply Chain model where the supply chain selected is by "direct truck." The supplier and buyer can be any be any NAICS industry, and the buyer can be any NAICS industry.

- **Type 4 (all other non-freight):** All other non-freight truck tours, including the transport of cargo that is not considered as a Type 3 tour, as well as all tours that only involve the provision of services, the transport of construction equipment or materials, etc.

The Supply Chain model output indicates the Standard Classification of Transported Goods two-digit code (SCTG2). This information, along with truck size, is used to convert the tons by truck to trucks. The conversion of tons per truck by Truck type and SCTG commodity was developed from Arizona records in the 2002 U.S. Vehicle Inventory and Usage Survey database.

Before converting from annual tons in the supply chain to daily trucks it is necessary to know the size of the truck, as medium or heavy, which will be used in the conversion from tons to trucks. The vehicle choice by Truck Tour Type is:

- **Tour Type 1 (freight)** in the delivery from, or pickup to, TLNs, is assumed to be only by heavy trucks.

- **Tour Type 2 (non-freight cargo delivery)** only applies to the use of medium trucks by wholesalers to deliver goods to their customers. These medium truck tours already are presumably included as weekday trucks in the truck tour model. There also is no need to convert from tons to trucks because the tour flow unit already is in trucks. What is needed is to scale the truck tours that begin in "Wholesalers" in the medium truck tour model.

- **Tour Type 3 (freight)** does not need a vehicle choice model. It is assumed that direct truck shipments of supply chain are by heavy (combination tractor trailer) trucks.

- **Tour Type 4 (non-freight)** does need a vehicle choice model, but that model already is implicitly being used in the medium and heavy truck tour models. Since these tours are, by definition, not related to the supply-chain model outputs, the vehicle choice does not change and need not be computed.

The process to convert from annual supply chain tons to daily truck trips is as follows:

- **Tour Type 1 (Freight):** Tours are developed using the outputs from the supply chain model. They are converted from annual tons to daily trucks as part of a two-step process. The tons are first converted from annual to daily using the 295 weekday equivalents. The daily tons at each stop, a supply chain output, of the tour is summed.

- **Tour Type 2 (non-freight cargo delivery)** do not need to be converted from tons to trucks. These are the "wholesaling" purpose tours that are estimated by the medium truck model.

- **Tour Type 3 (freight)** are reported in annual tons by heavy trucks and do need to be converted to daily TOD trucks. The annual trucks are converted to weekday trucks by diving by 295, the equivalent weekdays per year. It is assumed that the TOD distribution of Type 4 tours for heavy trucks, can be applied to the daily trucks.

- **Tour Type 4 (non-freight)** are by definition unrelated to the supply chain model tonnages. They already are expressed as weekday tours of medium and heavy trucks. While these tours do have to be unlinked from tours, with many legs, to trips for each individual leg, no conversion is required from tons to trucks. The TAZs of each stop on the tour become the origins and destinations of truck trips. The time of departure from a stop on the tour, determines the TOD period in which that trips is reported.

To predict the usage of heavy versus medium weight trucks by establishments in the MAG region, a logit model was employed. The data came from the 2016 MAG commercial establishment survey. This survey collected data at 416 establishments in the MAG region. From these establishments 229 had heavy or medium trucks based or making stops there. Respondents were asked about all arrivals, but only about the departures of those trucks based on location. The latter are analogous to the start of a truck tour. These data were expanded to produce a weighted dataset of truck behavior which was used for estimation.

The internal and external truck trip tables were combined but the truck classes—light, medium, and heavy—were retained. These three classes of vehicle trip tables were then assigned with the passenger auto trip tables in a multiclass equilibrium assignment. Several assignment runs were performed until the total truck volumes were validated against observed data (the validation performance measures of the model are described in the following sections). Trip assignment of the truck trips was completed using a user equilibrium highway assignment, and truck trips were assigned simultaneously with the passenger trips, because congestion has a significant impact on travel times experienced by trucks. Truck trips are assigned separately by type using the multiclass assignment technique for five vehicle types:

1. Single-occupant passenger vehicles.
2. High-occupant passenger vehicles with two or more occupants.
3. Light commercial trucks.
4. Medium trucks.
5. Heavy trucks.

The assignment validation is done at two different levels of geography. Screenline analysis includes some of the major freeways that pass through the region and carry a large volume of trucks in the region. These freeways include I-17 W, I-17 E, I-10 N, and I-10 S. Also included in these screenlines are Agua Fria, which is the river that flows through the west side of the MAG region while the Salt River flows just south of the Phoenix metro area.

MEMPHIS METROPOLITAN PLANNING ORGANIZATION TRUCK MODEL

Introduction

As “America’s Distribution Center,” the Greater Memphis Region plays a critical role in the Nation’s global supply chain, with the presence of major multimodal freight facilities and investments in freight infrastructure. Some of the main highlights include:

1. The presence of five Class I railroads (i.e., BNSF, CN, CSX, NS, and UP).
2. The busiest air cargo airport in the U.S. and the second busiest in the world.
3. The fourth largest inland port in the United States.
4. The Nation's third busiest trucking corridor, I-40, which connects the Atlantic and Pacific Coasts and runs directly through the Greater Memphis Region.

With such a heavy concentration of freight, it comes as no surprise that freight plays a very important role in the region's economy, with almost 30 percent of the employment concentrated in the freight industry.

General Information

Usage

The Memphis MPO uses its travel demand model to evaluate the impact of all highway vehicles, including trucks, during the development and evaluation of its Long-Range Transportation Plans and Transportation Improvement Programs. The Memphis MPO has limited jurisdiction over non-trucking freight modes, such as air, rail and waterborne modes. This case study describes how its travel demand model was updated to consider the impact of freight and non-freight trucks.

Methodology

While Memphis is a major freight hub, the Memphis MPO model deals primarily with highway travel. This consists of the freight portion of travel that is made by truck as well as all other travel by trucks. It was determined that there are substantial differences between the external and internal truck travel.

The external truck traffic, is primarily related to travel by freight as these movements are generally longer than non-freight trips/tours. While it was understood that freight is transported by modes other than truck, only freight travel by truck, including travel to and from freight terminals within the region was important to the MPO. The internal truck travel within the model region was primarily related to other truck uses.

The Memphis MPO truck model can be best characterized as a trip-based model, which considers truck freight as an external model and non-freight truck model as the internal model.

Coverage

Geography

The Memphis MPO is responsible for the transportation policy development, planning, and programming for Shelby and Fayette Counties in Tennessee and DeSoto and Marshall Counties in Mississippi. The MPO planning boundary covers all of Shelby County and DeSoto County and portions of Fayette County and Marshall County. The regional model for the Memphis MPO was recently updated as shown in figure 71.

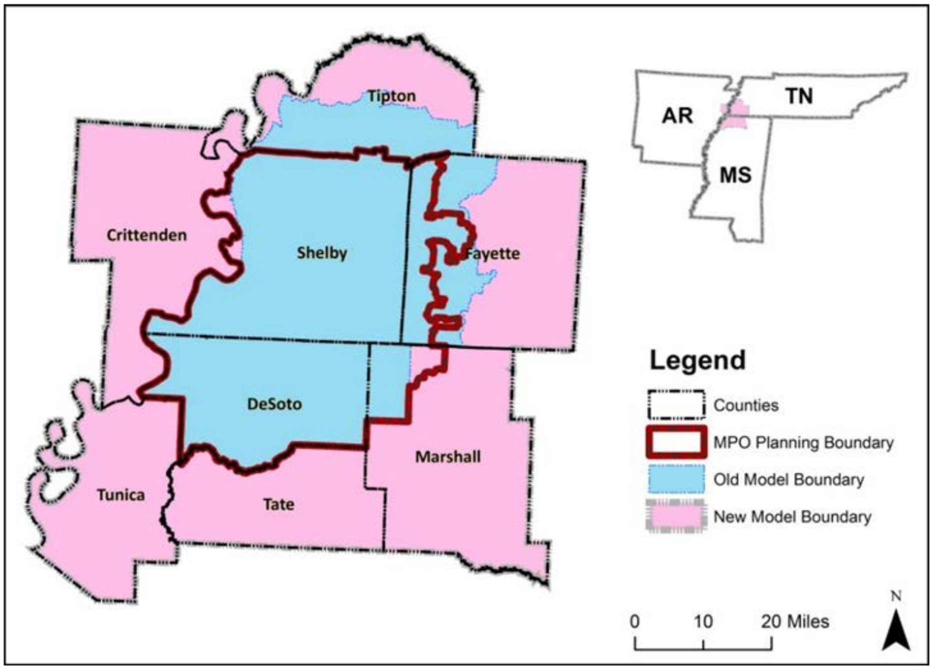

Figure 71. Map. Memphis metropolitan planning organization model boundary.
(Source: Memphis MPO Model Update Model Estimation and Validation Report.)

Modes

Four modes of transportation, including truck, rail, air and parcel (such as, U.S. Postal Service, UPS, and other couriers) are included in the supply chain model. The tour-based truck model includes light, medium and heavy trucks.

Commodities

SCTG commodities are grouped into the ten groups shown in table 47 for the external truck models.

Table 47. Commodity groups for external truck models.

Commodity Group		Daily Trucks Produced Internally (% of Internal-External)		Daily Trucks Attracted Internally (% of External-Internal)	
Name	#	Number	%	Number	%
Farm Products	1	222	6%	1,122	28%
Food Products	2	262	7%	242	6%
Sand and Gravel	3	277	7%	990	24%
Gasoline and Fuel	4	277	7%	324	8%
Chemicals	5	167	4%	47	1%
Nondurable Manufacture	6	91	2%	134	3%
Clay, Concrete, Glass	7	343	9%	168	4%

Table 47. Commodity groups for external truck models (continuation).

Commodity Group		Daily Trucks Produced Internally (% of Internal-External)		Daily Trucks Attracted Internally (% of External-Internal)	
Name	#	Number	%	Number	%
Durable Manufacture	8	120	3%	141	3%
Waste	9	232	6%	74	2%
Secondary and Mixed Freight	10	1,859	48%	827	20%
Total		3,850	100%	4,068	100%

(Source: Memphis MPO model.)

Forecast Details

Freight Trip Table

All freight truck trips are estimated as an external model that has one end inside the model area and the other end outside or pass through freight trucks. The main data source for the external truck models was TRANSEARCH data obtained from the Tennessee Department of Transportation (TnDOT). The information in this database was windowed to the Memphis model boundary. Table 47 shows the commodity groups that are used in the external truck models.

The external truck trip generation process required estimation of truck trip ends for both the internal and external ends of truck trips at the zone level. Internal zone truck trip ends were estimated as linear functions of employment by NAICS category.

Production and attraction equations were estimated for each commodity group using linear regression models. The initial estimation of rates for all commodity groups was calculated using the reported annual tons and converted to daily truck trip ends from TRANSEARCH for the counties in the Memphis MPO modeling region. Acceptable regression equations with zero intercepts were found between internal truck productions and NAICS employment at the county level, which was the most detailed geographic level reported in TRANSEARCH.

The assumption is that rates developed at county (i.e., district) level can then be applied to the same NAICS3 employment at the TAZ level. NAICS employment is calculated using Infogroup data served as the independent variables for the linear regression models. The estimated parameters are shown in table 48 (productions) and table 49 (attractions). These estimated coefficients were applied to model employment and other explanatory variables, such as population in each TAZ.

To confirm that these rates were reasonable, the estimated rates were applied to employment at a zonal level and compared to reported truck trips ends that originated in all Tennessee counties. For the proposed attraction rates, there was substantial agreement for all commodity groups. For productions, in all but one commodity group there was substantial agreement between the resulting estimated and reported truck trip ends. The one exception for the production rates was for the commodity group that includes Secondary and Mixed Freight. For this commodity group, the rate was estimated using all Tennessee counties. This produced the rate of 0.0173 daily external truck productions per NAICS 42, wholesale, employees, as well as the recommendation that 978 trucks/day be included as special generator external truck productions in Shelby County.

Table 48. External truck trip production rates for internal zones.

#	Commodity Group	2012 Daily Trucks		Variable		
		TRANSEARCH	Estimated	NAICS Categories	Coefficient	R^2 [1]
1	Farm Products	222	193	11	0.1931	0.85
2	Food Products	262	237	311	0.0497	0.97
3	Sand and Gravel	277	261	212, 213	2.3728	0.77
4	Gasoline and Fuel	277	215	324	0.2481	0.93
5	Chemicals	167	179	325	0.0275	1.00
6	Nondurable Manufacture	91	68	31, 32	0.0030	0.87
7	Clay, Concrete, Glass	343	405	327	0.4167	0.92
8	Durable Manufacture	120	104	33	0.0037	0.98
9	Waste	232	242	Total	0.0004	1.00
10	Secondary and Mixed Freight	1,859	1,544	42	0.01731	1.00

[1] R-squared (R2) is a statistical measure used for investment analysis and research that investors can use to determine a particular investment's correlation with (similarity to) a given benchmark.

(Source: Memphis MPO model.)

Table 49. External trip attraction equations for internal zones.

#	Commodity Group	2012 Daily Trucks		Variable			R^2
		TRANSEARCH	Estimated	NAICS Categories	Coefficient	t-stat[1]	
1	Farm Products	1,122	1,060	Pop	0.233	6.749	0.867
2	Food Products	242	205	42	1.837	11.105	0.946
3	Sand and Gravel	990	1,050	Pop	0.235	43.71	0.996
4	Gasoline and Fuel	324	332	Pop	0.074	33.458	0.994
5	Chemicals	47	45	42	0.402	69.516	0.999
6	Nondurable Manufacture	134	133	42	1.191	82.24	0.999
7	Clay, Concrete, Glass	168	164	Pop	0.037	38.603	0.995
8	Durable Manufacture	156	143	42	1.277	25.914	0.990
9	Waste	87	65	562	21.901	6.946	0.873
10	Secondary and Mixed Freight	786	768	42	6.875	62.933	0.998

[1] The t-statistic (t-stat) is the ratio of the departure of the estimated value of a parameter from its hypothesized value to its standard error.

(Source: Memphis MPO model.)

The distribution of the External-Internal (EI) and Internal-External (IE) daily truck trips was estimated using a standard gravity model distribution.

In this model, all internal-internal and external-external zonal interchanges were constrained to be zero by using a k-factor of zero. For the internal portion of the EI/IE trips, the productions and attractions are developed using the rates shown in table 48 and table 49 and applied to the TAZs.

The productions and attractions at the external stations for the Memphis MPO model region was developed from TRANSEARCH. At these external stations, the reported trucks represent not only the origins and destinations, but also the time traveled by trucks from all of North America in regions outside of the Memphis MPO model region until they reach the external stations.

The time within the region was computed using levels of service matrices from the Memphis MPO highway network.

The impedance function in the gravity model requires a time which includes both time within the Memphis MPO model region, and the average time at those external stations for travel to and from the external zones. A windowing procedure that calculated average impedance between the external stations and all TRANSEARCH zones was calculated. This was done for each commodity group separately since different commodities come from different external regions. The resulting average time between all external TRANSEARCH zones and the external stations served as an input to the gravity model.

The gravity model was applied where the impedance between a Memphis TAZ and an external station was the addition of the time within the region, as found by skimming the Memphis MPO highway network, and the average time between that external station all external TRANSEARCH zones. The truck volumes at the external stations of the Memphis MPO model include not only the EI and IE trucks but also the External-External (EE) trucks that pass through the Memphis MPO model region without stopping.

The truck counts at the external stations include EI, IE and EE travel. The truck counts were as reported by TnDOT, Mississippi DOT, and Arkansas DOT, or if neither DOT had truck counts available for an external station, from the daily truck volumes reported in the FAF 3.4 network for the links on which these externals stations were located.

The TRANSEARCH table that was windowed to the Memphis MPO model region was aggregated over all ten Commodity Groups and served as the initial seed matrix. An adaptation of Fratar trip balancing with the windowed TRANSEARCH tables as the seed table and the observed truck counts as constraints at the external stations was then run producing a truck trip table consistent with the counts.

Travel between external stations in the output truck trip table represented the EE truck table that was used in the Memphis MPO model. The cells in the row of internal zones represent the portion of trucks at an external station that should be associated with internal attractions. Similarly, the cells in the columns of internal zones represent the portion of total trucks at that stations that are the external attractions at those stations that should be associated with internal productions.

After the Fratar trip balancing process, TRANSEARCH trucks at each external station were adjusted to be consistent with observed trucks. This creates both the EE truck table and the sum of the External truck productions and attractions at each external station. Using the share of trucks by Commodity Group, the external station truck productions and attractions were allocated to each Commodity Group. In addition to adjusting the windowed TRANSEARCH trucks to the observed trucks, the base year and forecast TRANSEARCH trucks windowed to the Memphis MPO model region were also used to develop growth factors that should be applied to the external portion of EI/IE trips, but also to the EE truck table. These factors were calculated by comparing the TRANSEARCH future year daily trucks with the base year TRANSEARCH daily trucks for each Commodity Group at each external station.

Non-Freight Trip Table

The internal model includes all trucks, not just those trucks that carry freight. Therefore, the TnDOT TRANSEARCH database is not appropriate to develop the internal truck model. A different dataset that captures all truck movements within the region was used for the internal models. This section outlines the internal truck generation and distribution models.

TnDOT provided a trip table of heavy trucks between its Statewide Model (SWM) TAZs that was inferred from ATRI GPS records. This truck trip table does not include medium and light truck trip ends.

The ATRI inferred truck trip ends for statewide model TAZs within the Memphis MPO model region were regressed against employment, and households from Memphis TAZs that were aggregated to SWM TAZs. The independent variables used in this regression were limited to the explanatory variables that were used in the original QRFM (QRFM I). This QRFM includes default parameters for light, medium, and heavy trucks. The results of this regression provide a production rate for heavy duty truck trips. The relationship between the default QRFM I and the new estimated parameters for heavy trucks was calculated. This relationship provides an explanation of local conditions. These same adjustment rates were then applied to the default QRFM I rates for medium and light trucks to produce inferred rates for each class of trucks that could be used in the Memphis MPO model.

As is conventional for internal truck models, including the QRFM I, by definition, the rates shown in table 50 apply for both truck productions and attractions. This includes the default QRFM I rates as well as the rates calculated by a regression with Memphis ATRI.

Table 50. Internal truck production/attraction rates default Quick Response Freight Manual I versus American Transportation Research Institute regression.

Variable	QRFM Trucks			ATRI trucks
	Light	Medium	Heavy	TN SWM TAZs
				R^2=0.652
Agriculture, Mining and Construction	1.11	0.289	0.174	0.5040
Manufacturing, Transportation, Communications, and Utilities (TCU) and Wholesale Trade	0.94	0.242	0.104	0.9420
Retail Trade	0.89	0.253	0.065	0.7840
Office and Services	0.44	0.068	0.009	0.0001
Households	0.25	0.099	0.038	0.0001

(Source: Memphis MPO model.)

The coefficients for office/service employment and households in a regression with the inferred ATRI truck trip ends resulted in negative or otherwise statistically inappropriate coefficients.

These variables were excluded from further regressions and their coefficients were set to a minimal value.

The comparison between the default QRFM rates for heavy, combination unit tractor trailer, truck and the ATRI regressions for these same trucks, was applied to the remaining QRFM truck types. The adjusted rates are shown in table 51.

Table 51. Internal truck production/attraction rates adjusted rates trucks per day per employee (household).

Variable	Light	Medium	Heavy
Agriculture, Mining and Construction	3.2152	0.8371	0.504
Manufacturing, TCU and Wholesale Trade	8.4961	2.192	0.942
Retail Trade	10.7106	3.0516	0.784
Office and Services	0.0049	0.0008	0.0001
Households	0.0007	0.0003	0.0001

(Source: Memphis MPO model.)

In addition to establishing proposed heavy truck trip generation rates, the regression of the ATRI truck trip ends with the explanatory data that was used to identify special generators. Special generators are those locations where the explanatory variables alone do not explain all observed trip ends.

The location and value of these special generators was determined by examining outliers to the regression which were more than ½ of a Standard Deviation from the estimated regression line, are shown in table 52. Also shown is an estimate of the special generators that were added at this location, defined as the difference between the inferred trips and ½ of a Standard Deviation from the estimated regression line. These locations were observed to be associated with expected intermodal facilities that would be expected to generate truck trip ends in excess of explanatory employment at that facility.

Table 52. Special generator locations.

SWM TAZ	ATRI Inferred	Estimated from Regression	Potential Special Generator	Facility
2456	15,905	5,751	11,939	BNSF Memphis IM Yard
2457	13,355	6,662	8,801	BNSF Memphis IM Yard
2484	7,119	3,518	4,720	BNSF Memphis IM Yard
2518	9,997	1,682	8,839	Port of Memphis

(Source: Memphis MPO model.)

Truck trips in the QRFM I were distributed through the use of the standard gravity model. The impedance function in that gravity model is a standard exponential decay function of travel time.

In these functions, the parameter applied to the travel time is the negative inverse of the average travel time. The average travel time for ATRI internal-internal truck trips was calculated from the product of the ATRI inferred truck trips and the travel times between TnDOT SWM TAZs. The relationship between these calculated average travel times, converted to the coefficient of the impedance function of the gravity model, can be compared to the default coefficients in the QRFM. As in the internal truck generation model, the calculated ATRI trip distribution parameter for heavy trucks was compared against the default QRFM parameter. That relationship was applied to the default QRFM coefficients for other truck types to calculate the proposed coefficients to the trip distribution impedance function for medium and light trucks. These are shown in table 53.

Table 53. Internal trip distribution parameters.

QRFM Trucks			ATRI Trucks	
Category	**Coeff**	**1/ Coeff**	**Coeff**	**1/Coeff**
Light	*-0.080*	*12.5 min*	*-0.249*	*4.02 min*
Medium	*-0.100*	*10.0 min*	*-0.310*	*3.22 min*
Heavy	-0.030	33.3 min	-0.093	10.7 min

(Source: Memphis MPO model.)

It was observed that the adjustments to the impedance function required a considerable reduction to the default QRFM I impedance function coefficient and the adjustments to the default QRFM I truck trip generation rates required a consideration increase. To ensure that the combined use of these adjusted values is consistent with observed truck counts, an ODME was performed. The ODME process uses the internal-internal truck tables created as a result of using the proposed adjusted parameters as a seed and is constrained by observed truck counts on highway links internal to the Memphis region.

The internal-internal truck table created using the proposed equations was consistent with the truck counts. While the proposed trip generation rates might be too high and the proposed trip distribution impedance function might be too low, this would result in a larger than expected number on intra-zonal truck trips. These intra-zonal trips would never be assigned. Thus, even though the internal model truck parameters might be too high/low, the resulting inter-zonal portion of the resulting truck trip table would still be consistent with observed truck counts and the use of the TnDOT supplied ATRI inferred truck trips as an estimation dataset for internal-internal truck trips was justified.

Model Network Assignment

The highway assignment has two steps: a multimodal multiclass assignment (MMA) all-or-nothing assignment and an MMA user equilibrium assignment. The initial all-or-nothing assignment is used to “preload” through trips and large commercial vehicle trips, which are less sensitive to travel time and do not reroute trips based on congestion as often as trips such as an internal home-based-work auto trips. The MMA assignment is a generalized cost assignment that assigns trips by individual modes or user classes to the network simultaneously. This setup offers several advantages, including the flexibility to model High Occupancy Vehicle (HOV) lanes, toll lanes, and passenger car equivalencies for trucks.

The two steps of assignments (preload and equilibrium) are applied for each of the four time periods (AM, midday, PM, night), which yields a total of eight assignment routines for the Memphis model. Volume delay functions used for the assignment are based on time and period capacity and are modified versions of the Bureau of Public Road (BPR) curves. The volume-delay curves have varied coefficients for different area types, functional classifications, and link speeds. These curves were reviewed and adjusted during the calibration process.

NEW YORK METROPOLITAN TRANSPORTATION COUNCIL’S BEST PRACTICES MODEL

Introduction

The New York Metropolitan Transportation Council (NYMTC) is the metropolitan planning organization for a ten-county area, including New York City, Long Island, and the lower Hudson Valley in the State of New York. NYMTC’s travel demand model is the New York Best Practice Model (NYBPM).

General Information

The NYBPM is used to perform the Federally-required Transportation Conformity Determination and Regional Emissions Analysis, and to assess projects in the Regional Transportation Plan and Transportation Improvement Program (TIP). NYBPM provides measures for the congestion management process (CMP) and facilitates major investment studies, sub-regional and corridor-level analyses, and project studies in the region.

The 2010 base year update of the NYBPM was completed and released in early 2015. This version includes an updated census-based TAZ system, a transportation network update, a truck and commercial van model, an external model, 2040 forecast validation, development of a time of day choice model, and improvement of the destination choice model. NYBPM is currently undergoing an update using a 2012 base year.

Methodology

The NYBPM is an activity/tour-based model for regional demand forecasting with the following characteristics:

- Tours (or paired journeys) are used as the basic unit of modeling.
- The conceptual framework of daily activity of individuals accounts for intra-household interactions and constraints on peoples' travel in time and space.
- A microsimulation approach is used to generate forecasts that are discrete choices for individuals.
- Stop frequency and stop locations are modeled.
- Nonmotorized mode is analyzed as a separate mode.

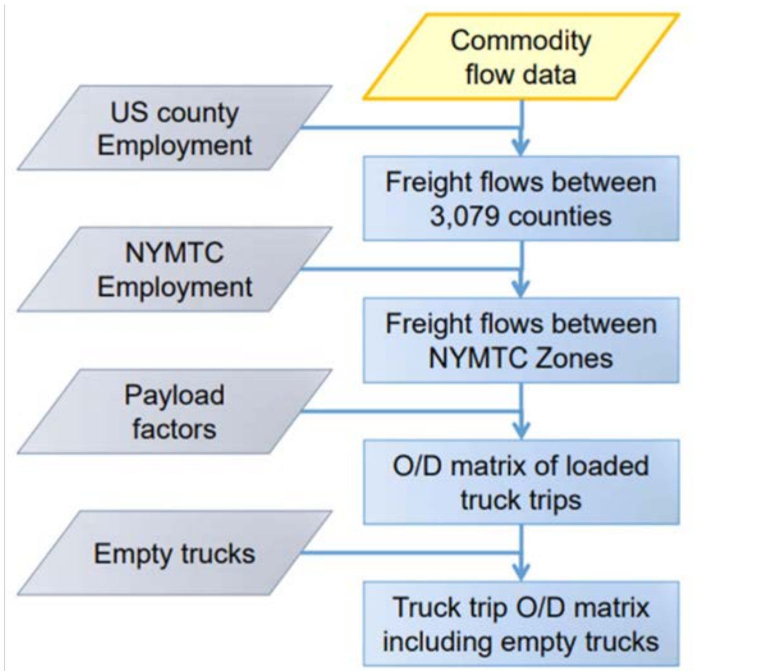

Figure 72. Flowchart. Long-distance truck model design.
(Source: "Progress Report on External and Truck Model 2," NYMTC, 2015.)

Coverage

Geography

NYBPM models short-distance truck trips (less than 50 miles) and long-distance truck trips (greater than 50 miles) separately. As figure 73 shows, the long-distance trips cover FAF zones, aggregated to the State level across most of the country. County-level detail is available within 50 miles and the NYBPM model territory, illustrated in gray. Non-freight trucks include empty trucks, estimated as part of the freight model, and local trips by commercial vans, estimated using NYBPM's commercial van (CV) model.

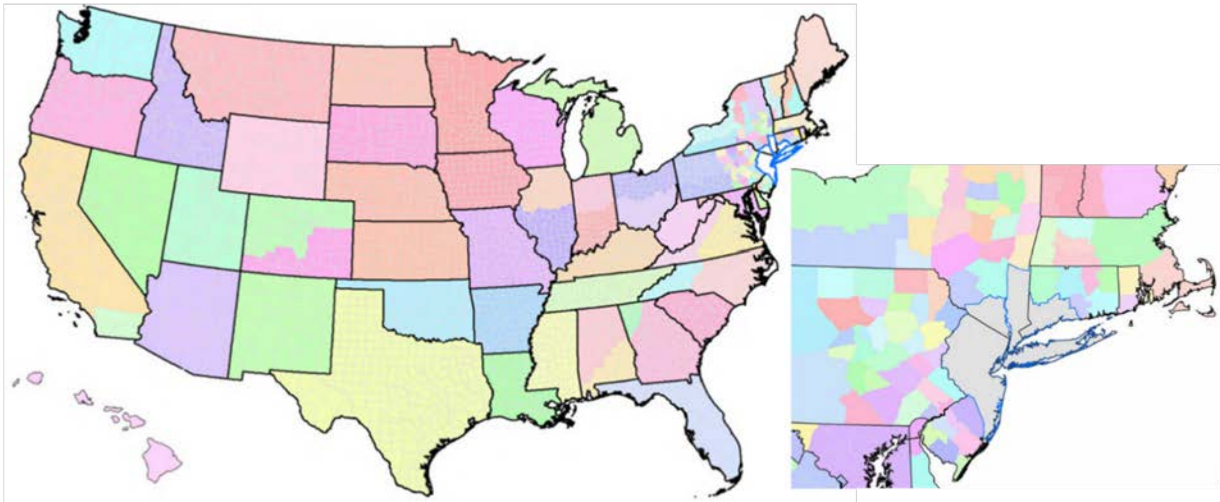

Figure 73. Map. National and regional zones.
(Source: "Progress Report on External and Truck Model 1," NYMTC, 2013.)

Modes

Truck is the only freight mode in NYBPM, however there is a distinction between two truck vehicle types to include varying values of time, differences in tolls and different impacts on congestion due to truck length and the ability to accelerate. The two truck vehicle groups are multiple unit/heavy trucks (four or more axles) and single unit/medium trucks (two and three axles). By definition non-freight trucks are truck mode.

Commodities

NYBPM does not distinguish commodity types. Empty freight trucks are not separated from other non-freight trucks.

Forecast Details

Freight Trip Tables

NYBPM uses FAF commodity flow data to estimate and forecast commodity truck demand nationally, applying payload factors and weekday factors to convert FAF tons to daily commodity trucks, and applying multipliers to estimate empty truck trips.

For short-distance truck trips, an origin-destination matrix estimation (ODME) process produces truck trip tables. The process begins with the development of a seed matrix that uses QRFM generation rates for several industry categories (agriculture, manufacturing, retail, office, and households) and subtracts long-distance and short-distance border trips that cross external stations at the edges of the NYBPM model territory. The long-distance and short-distance border trips are estimated using a calibrated FAF-based model and gravity model. These trips are subtracted from the ODME result (or set to zero where the difference produces a negative number) to produce one target short-distance trip table for each time of day period (AM, midday, PM, and night). Trip productions are regressed using zonal employment data for 20 industries classified by NAICS codes. A separate regression is estimated for each time-of-day period.

Flow direction	Short-distance (≤ 50 miles)	Long-distance (> 50 miles)
Internal-Internal	Use short-distance truck model	
Internal-External	Use long-distance (or FAF-based) truck model and short-distance truck flows crossing external stations	
External-Internal		
External-External		

Figure 74. Sample chart. Short- and long-distance truck definitions and processing.
(Source: User's Guide for the NYBPM 2G Model in TransCAD 6.0, NYMTC, 2012.)

Non-Freight Trip Table

The methodology used for modeling vans closely resembles the design of the short-distance truck model. This ensures consistency throughout commercial vehicle modeling and benefits from economies of scale if a similar method is applied twice. The combination of ODME with multiple regression helps in overcoming many shortcomings of the current van model implementation. The methodology consist of the following six steps:

1. The 1996 version QRFM provides trip generation rates for four-tire non-freight commercial vehicles. These rates were used for the initial estimate of a van trip table. Subsequently, these rates were adjusted to New York-specific van travel behavior.

2. A survey conducted for the North Carolina Triangle region (Raleigh) has been used as a placeholder until more local data become available. A gravity model was used to model a van trip table.

3. ODME has been used to estimate a reasonable van trip table. ODME adjusts the QRFM trip table to match count data as well as possible.

4. Trip productions and trip attractions are calculated using the column and row totals of the ODME trip table. These trip productions and attractions are disconnected from actual activity in each zone (i.e., population and employment), they purely represent an artificial trip table that generates trips that match traffic counts.

5. A stepwise multiple regression has been implemented, where ODME trip productions is the dependent variable and independent variables are employment by type, households by income, density, area type and other zonal attributes. This step re-estimates QRFM trip production and attraction rates and embellishes these rates with additional zonal attributes.

The revised trip generation and attraction rates are used in the NYBPM van model.

Modal Network Assignment

The resulting truck trip tables are used as inputs to the TransCAD multiclass assignment.

The NYBPM network has four weekday periods—AM peak (6:00 a.m.–10:00 a.m.), midday (10:00 a.m.–4:00 p.m.), PM peak (4:00 p.m.–8:00 p.m.), and night (8:00 p.m.–6:00 a.m.). The NYBPM highway network contains more than 60,000 links, including most minor arterial roadways and above-roadway facilities. The database includes information on number of lanes, functional class, speed, parking restriction, truck usage. The network includes the following provisions to account for truck regulations:

- Truck designated routes (through truck).
- Truck permitted routes (local routes).
- All trucks always prohibited (mostly parkways).
- Heavy trucks always prohibited (Holland tunnel).

The network also includes toll rates applicable to each of the two classes of truck traffic.

The highway network assignment process begins with loading the network with the six-highway mode vehicle trip tables (including truck and commercial vans) for each of the four times of day. Multiple iterations (internal) of the assignment are performed, with a relative gap convergence criteria of 0.005 set as the default, requiring about 50-100 iterations. Applying the general user equilibrium Multi-Class highway assignment in TranCAD, generates “loaded” highway network link files that contain forecast link volumes, broken down by vehicle class, and estimated speeds.

The scenario forecasting process includes developing four global iterations of the entire model, with the trip tables and link volumes of the intermediate iterations averaged to promote convergence. The final iteration is un-averaged, and produces the scenario forecast.[17]

[17] User’s Guide for the NYBPM 2G Model in TransCAD 6.0—Caliper Corporation. (2012) Final Report prepared for the New York Metropolitan Transportation Council (NYMTC).

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