Behavioral/Agent-Based Supply Chain Modeling Research Synthesis and Guide

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16. Abstract There are now a handful of public agencies in the United States that have developed, or are in the process of developing, behavioral/agent-based models of supply chain decisions and freight movements, due in part to funding from FHWA Broad Agency Announcement awards and the SHRP2 C20 program. This guidance document provides a vital role in ensuring that the experiences of early adopters are more widely disseminated, thereby enabling other public agencies to develop similar models, or at least assess their feasibility.			
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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations

AB	Activity-Based
ACE	Agent-Based Computational Economics
ADOT	Arizona Department of Transportation
ATRI	American Transportation Research Institute
BEA	U.S. Bureau of Economic Analysis
BMC	Baltimore Metropolitan Council (Maryland)
BTS	U.S. Bureau of Transportation Statistics
CBP	County Business Patterns
CFS	Commodity Flow Survey
CMAP	Chicago Metropolitan Agency for Planning (Illinois)
CSA	Compliance, Safety, Accountability
CVTM	Commercial Vehicle Touring Model
DOT	Department of Transportation
DPPA	Drivers Privacy Protection Act
DSA	Data-Sharing Agreement
FAF	Freight Analysis Framework
FAME	Freight Activity Microsimulation Estimator
FCRA	Fair Credit Reporting Act
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FICO	Fair Isaac Corporation
FLSWM	Florida Statewide Model
FOIA	Freedom of Information Act
FPM	Freight Performance Measures
FTTM	Freight Truck-Touring Model
GIS	Geographic Information System
GPS	Global Positioning System
IMPLAN	Impact Analysis for Planning
IO	Input-Output
LEHD	Longitudinal Employer-Household Dynamics
MAG	Maricopa Association of Governments (Arizona)
MCMIS	Motor Carrier Management Information System
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organization
MSTM	Maryland Statewide Model
MVR	Motor Vehicle Record
NAICS	North American Industrial Classification System
NETS	National Establishment Time Series
NHS	National Highway System
NSCM	National Supply Chain Model
NTAD	National Transportation Atlas Database
O-D	Origin-Destination
ODOT	Oregon Department of Transportation

ORNL	Oak Ridge National Laboratory
PAG	Pima Association of Governments (Arizona)
PIERS	Port Import/Export Reporting Service
PM	Performance Measures
PMG	Procurement Market Game
PUM	Public Use Microdata
SCTG	Standard Classification of Transported Goods
SHA	State Highway Administration
STCC	Standard Transportation Commodity Code
SWIM	Statewide Integrated Model (Oregon)
TAZ	Traffic Analysis Zone
USDA	U.S. Department of Agriculture
USDOT	U.S. Department of Transportation
VHT	Vehicle Hours Traveled
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle Miles Traveled
WIM	Weigh-in-Motion
WisDOT	Wisconsin Department of Transportation

EXECUTIVE SUMMARY

Freight planning has received significant attention in recent years, not only due to Federal emphasis on freight in the Moving Ahead for Progress in the 21st Century (MAP-21) Act and the Fixing America's Surface Transportation (FAST) Act, but also because of the vital role freight plays in the economy. Transportation agencies are increasingly examining details of freight forecasts to better understand supply chain decisions and ways to improve freight mobility. In addition, the trucking industry is on the verge of transformation with automated and connected vehicle technologies and drone deliveries. Freight forecasting models need to be sensitive to the elements of this ever-changing environment so that scarce transportation funding can be targeted towards improvements that will have the greatest benefit on freight movement.

Historical freight modeling focused primarily on direct truck trips, but the dynamics of the mode choice and the supply chain aspects of freight movements have become critical for better understanding implications for planning. Advanced behavioral/agent-based freight models are now being developed that consider supply chain and delivery systems to provide a more complete understanding of freight movement and forecasting. While transportation planning agencies have begun developing advanced behavioral/agent-based freight forecasting models, existing literature and research is limited in scope and detail. The advent of Federal research into advanced freight models has provided an opportunity to collaborate across agencies and build new methodologies to address these challenges. This report describes the experiences with advanced supply chain freight travel demand modeling.

This project evaluated seven State and regional agencies and summarizes the scope and details of their behavioral-based supply chain freight models. These included all the behavioral-based supply chain freight models in the United States (models from Chicago, IL, Florida, Maryland, Portland, OR, Phoenix, AZ, Oregon, and Wisconsin). The reviews evaluated the methods used in terms of freight modeling needs, model structure, market segmentation, assumptions, performance measures, approach to forecasting, and types of applications. The reviews also identified data used for inputs, estimation, calibration, and validation along with any data that was desired but not available.

These advanced behavioral-based supply chain freight models are disaggregate models that incorporate supply chain procedures and truck touring aspects. The common components/approaches to advanced behavioral-based supply chain freight models are summarized below and illustrated on the following page:

- Firm synthesis includes freight production and consumption.
- Commodity flows include buyer-supplier matching and commodity flow allocation.
- Transportation/logistics include distribution channel, vehicle choice and shipment size.
- Modal assignment.
- Network flows include truck touring models.

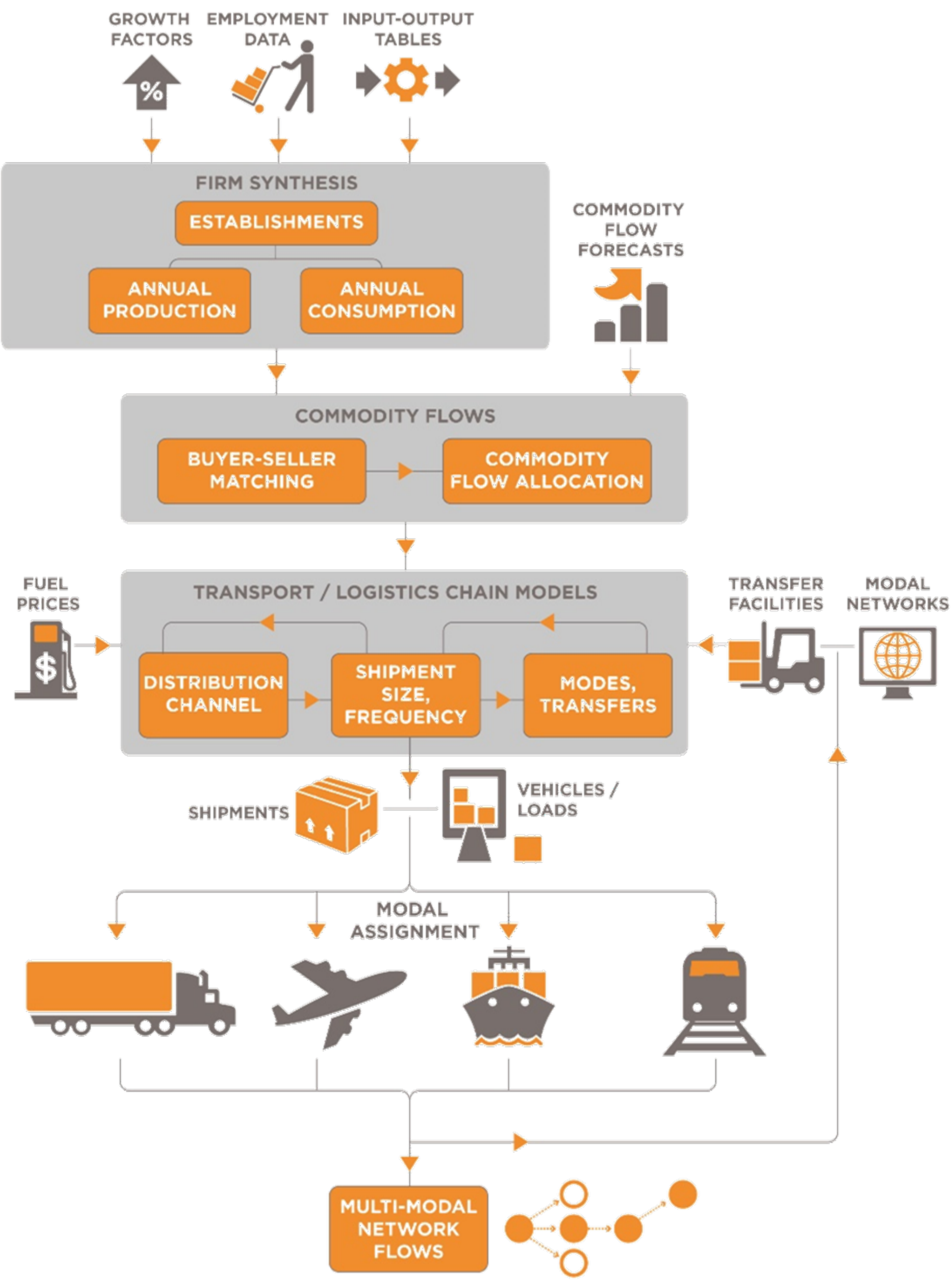

Figure E-1. Behavioral Supply Chain Modeling Process.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

The elements of a freight model design rely on traditional multinomial and nested logit choice model formulations. The first step of these supply chain models is an enumeration of establishments based on iterative proportional fitting methods. The buyer-supplier matching model component is based on different methods, with the most advanced being a game theory application. Buyers consider several transportation, logistics, risk, capacity, and productivity factors for sellers when selecting a seller. Some buyer-supplier matching models use fuzzy logic or agent-based computational economics. Tour-based truck models primarily use the multinomial logit choice approach, combined with the traveling salesman problem algorithm. In several cases, the stop-sequencing element of the truck-touring models used a different approach, such as the greedy algorithm and the hurdle/count model.

Data is another vital element of a freight model. Limited availability of data on goods movement previously hampered freight models; however, recent sources of new data combined with new methods have allowed freight models to advance. There are national freight datasets that are publicly available to develop inputs to freight models in combination with State or regional data. New data sources collected from mobile or navigational systems have provided opportunities for calibration and validation of advanced freight models.

Technological advances associated with collecting business information have been exponential, leading to a massive increase in the amount of data that is generated, stored, and distributed. The internal and external sharing of data is crucial to most business operations. It forms the basis for most business decision-making processes and models. Conversely, the protection of these data, which are often proprietary in nature, is essential to reducing risk and liability and is a necessity for firms competing in a free market. Public transportation agencies can consider arrangements with private data firms or confidentiality agreements to obtain data needed for behavioral supply chain freight models while protecting data privacy.

Advanced behavioral/agent-based freight models provide improved tools to better understand supply chain decisions and the policy levers for improving freight mobility. This can provide critical data to support performance measures that evaluate freight policies and programs. Typical freight performance measures include tonnage or value of goods moved, cost per ton, import and export tonnage or value, modes shares, and market shares of international or domestic trade. Freight volumes, travel times, and speeds are important means of measuring performance of the system along with other measures for operations, finance, and safety.

An agency’s decision to transition to a more advanced freight model structure must weigh the investment cost of transitioning against the importance of answering detailed policy and planning questions.

CHAPTER 1. INTRODUCTION

PROJECT PURPOSE AND NEED

A handful of public agencies in the United States are in the process of developing—or have already developed—behavioral/agent-based models of supply chain decisions and freight movements. The increase in development of these new models is largely attributable to funding from the Federal Highway Administration (FHWA) Broad Agency Announcement awards and the Strategic Highway Research Program (SHRP2) C20 program, which aims to foster fresh ideas and new approaches to designing and implementing freight demand modeling. The main purpose of this synthesis is to evaluate recent advancements in these behavioral/agent-based models and support the broader application of these methods to forecast future freight flows. This synthesis document is intended for managers of travel demand modeling systems and other technically oriented staff of federal, State, and regional transportation planning agencies who have an interest in behavioral/agent-based modeling of freight flows. Public agencies interested in developing behavioral/agent-based freight models can use this synthesis to assess the feasibility and practicality of developing similar models for their own regions based on the experiences of other agencies.

APPROACH

As part of this synthesis, agent-based supply chain freight models currently in use by the Chicago Metropolitan Agency for Planning (CMAP), Florida Department of Transportation (FDOT), Wisconsin Department of Transportation (WisDOT), Phoenix's Maricopa Association of Governments (MAG), Oregon Department of Transportation (ODOT), Baltimore Metropolitan Council (BMC), and Metro (Portland, Oregon) were reviewed. Each of the models reviewed are summarized along the following 12 dimensions related to methodology and data.

Methodology

- Determine supply chain modeling needs.
- Determine model structure, component interactions, and segmentation.
- Develop market segmentation (industry, commodity, mode, vehicle type, temporal, activity type).
- Determine modeled performance measures.
- Develop approach to forecasting.
- Understand types of applications and procedures.

Data

- Determine geographic scope.
- Develop data inputs.

- Determine data used for estimating model parameters, model calibration, and model validation.
- Determine data desired, but not found.

Many of the freight models reviewed as part of this synthesis were found to rely on data from publicly available sources such as the Freight Analysis Framework (FAF).[1] The second chapter on common datasets includes descriptions of common data sources used by some of these freight models reviewed as part of this synthesis.

CONTENTS OF THIS REPORT

In addition to the introduction, this synthesis and guide includes four additional chapters:

1. Chapter 1 provides an introduction and overview of this synthesis and guide.
2. Chapter 2 describes modeling needs, concepts, terminology, and common modeling approaches used in behavioral supply chain models.
3. Chapter 3 describes the data required to support a behavioral supply chain model. This chapter also describes the common datasets used in behavioral/agent-based supply chain models.
4. Chapter 4 includes a comprehensive model review that was developed after reviewing model documentation and contacting State departments of transportation (DOTs) and metropolitan planning organizations (MPOs) that have implemented, or are in the process of implementing, behavioral/agent-based supply chain models.
5. Chapter 5 describes how State DOTs and MPOs can assess and prepare for supply chain model readiness.
6. Chapter 6 describes freight performance measures used by public and private sector.
7. Chapter 7 describes public and private sector data sharing and issues. This chapter also discusses the success that some public agencies have had in finding collaboration opportunities to obtain or use freight model data.

Chapters 2 and 3 include discussion of common data sources that support the development of a behavioral supply chain model along with common modeling approaches.

Chapter 4, the comprehensive model review, uses information collected from seven public agencies. The project team used this information to develop this synthesis of best practices and lessons learned, as communicated by each agency. This chapter is based on the findings of the state-of-the-art model review. The models are presented in the order of the development date with the earliest developed model, described first.

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[1] The Freight Analysis Framework (enumerated web address: https://ops.fhwa.dot.gov/freight/freight_analysis/faf/).

Chapter 5 helps agencies assess whether a behavioral or agent-based supply chain modeling approach is right for their needs and discusses considerations when planning for model development. Chapter 6 discusses public and private sector's freight performance measures. In addition, Chapter 7 describes data sharing issues and arrangements between public and private sectors.

CHAPTER 2. SUPPLY CHAIN MODELING NEEDS AND CONCEPTS

FREIGHT MODELING NEEDS

Travel models are analytical tools designed to provide quantitative input to help answer questions that arise during the policy and planning decision-making process. In the past, many transportation agencies were faced with relatively simple questions, such as how best to allocate highway construction funding to provide capacity in their study area for expected growth in vehicular travel. As agencies are faced with more complex policy and planning questions, the complexity of travel models has increased to provide the necessary level of detail and policy sensitivity. Passenger travel modeling has led the way in recent years with the gradual transition from trip-based models to activity-based (AB) models among larger agencies in the United States. Freight modeling is undergoing a similar transition to answer increasingly complex freight transportation-related policy questions faced by agencies.

The agencies that participated in this synthesis expressed the need to answer questions posed as part of their planning processes that were beyond the capabilities of their traditional trip-based freight and truck modeling tools. For example, the following policy analysis needs and issues were identified as reasons for implementing a supply chain freight model:

- Understand the economic impacts of freight and the relationship between changes in the economy and changes in demand for freight transportation:
    - Address the economic impacts of freight transportation-based changes in the economy and freight delivery systems.
    - Explain economic choices made for goods movement across multiple modes and commodities.
    - Provide a picture of the study area's role in the national freight economy, including the economic competitiveness of the study area compared to other areas.
    - Understand the effects of the evolution of industry in the study area (transition to emerging industries such as aerospace, clean energy, life sciences, and creative industries).
    - Understand the connections between the economy of the study area, the resulting demand for freight movement, and the performance of the transportation system in a complex and congested region.
    - Develop freight forecasts that are responsive to changes in economic forecasts, changing growth rates among industrial sectors, and changing rates of economic exchange and commodity flows between sectors.
    - Provide inputs regarding how freight transportation will contribute to economic recovery.
    - Evaluate technological shifts in logistics and supply chain practices (e.g., near-sourcing, outsourcing, productivity enhancements).

- Understand the relationships between freight movement and land-use and spatial development in a study area:
  - Increase understanding of freight-generating industrial and commercial development and how these land uses relate to goods movement, including first and last mile.
  - Deliver insight into how land use, local economic development and demographic factors drive freight movement, trip generation, and freight demand analysis.
  - Incorporate the evolution of land-use patterns in freight-related industries, such as increased development of intermodal logistics hubs and larger regional distribution centers.
- Understand current freight movements in a study area:
  - Provide an understanding of how freight currently moves throughout the study area.
  - Provide an understanding of truck touring for urban goods delivery and service trips.
  - Represent long-distance truck movements and empty truck movements.
- Evaluate complex freight-related policies and freight-related infrastructure improvements:
  - Evaluate the transportation impacts of freight policies such as overnight delivery ordinances or the expansion of logistics terminals within the region.
  - Anticipate the effects of freight-related government and private sector decisions that affect the transportation system and its uses.
  - Evaluate the local freight distribution system, the impacts of port expansions, and improvements to intermodal facilities.
  - Support comprehensive analysis of infrastructure needs and policy choices pertaining to the movement of goods.
  - Provide a freight forecasting model for an extensive and complex study area that includes the operations of several significant industries with connections to major freight ports and the U.S. border.
- Understand the environmental impacts of freight and truck movements.
  - Develop more detailed network assignments by truck type to support environmental analysis.

In most cases, the freight models used by agencies in this report were designed to support the needs of multiple stakeholders in large and complex regions, which added to the diversity of policy needs and issues. For example, several of the freight models were designed to cover megaregions with multiple Metropolitan Planning Organizations, or large single-Metropolitan Planning Organization regions, or were jointly developed by State and regional agencies. In several cases, modal agencies, such as port authorities, were involved in the development of the freight models. This expansion beyond a more historically typical highway-focused use of travel models added to the need to cover all freight transportation modes rather than, for example, a truck-only model.

Table 1. Summary of Freight Modeling Needs, by Type.

Type	Economic Forecasts	Growth Rates by Industry	Logistics Practices	Roadway Congestion	Private Sector Operations	Logistics Terminals	Ports	Truck Volumes
Economic Impact	✓	✓	✓	✓	✓	✓	✓	
Land Use		✓			✓	✓	✓	
Policies	✓	✓	✓			✓	✓	
Infrastructure				✓		✓	✓	✓
Environmental				✓	✓	✓	✓	✓

Table 1 summarizes agencies' freight modeling needs, by type. This demonstrates what elements of freight modeling needs influence the five categories of need (economic impact, land use, policies, infrastructure, and environmental).

COMMON MODELING METHODS

Approaches to freight travel demand modeling in the United States range from conventional four-step planning models to more advanced integrated supply chain, economic-based, and tour-based models. This synthesis describes the experiences of public agencies in the United States with advanced supply chain freight travel demand modeling.

The traditional four-step freight demand modeling approach is defined by its four sequential stages of trip generation, trip distribution, modal split, and traffic assignment. In these models, the demand modeling process is aggregate and trip-based or commodity-based with limited analysis of individual trip behavior.

Four-step models are relatively weak in terms of behavioral foundation, which often leads to limited model capabilities and model accuracy issues. These models fail to model the underlying economic behaviors from which the demand is derived. The main drawback of these aggregate models is their inability to capture the complexity of freight policy systems and their failure to replicate the supply chains and logistics decisions made by individual players in the freight supply chain.

To address some of the limitations mentioned above, advanced freight demand forecasting models have been proposed. These advanced models are disaggregate models that incorporate supply chain procedures or truck touring aspects. Disaggregate freight models can also provide more capabilities than aggregate models to evaluate policies and investments.

The following text describes common components/approaches to advanced supply chain modeling, including firm synthesis, buyer-supplier matching, distribution channel and vehicle choice, shipment size, mode choice, and truck touring models. Figure 2 shows a supply chain modeling process.

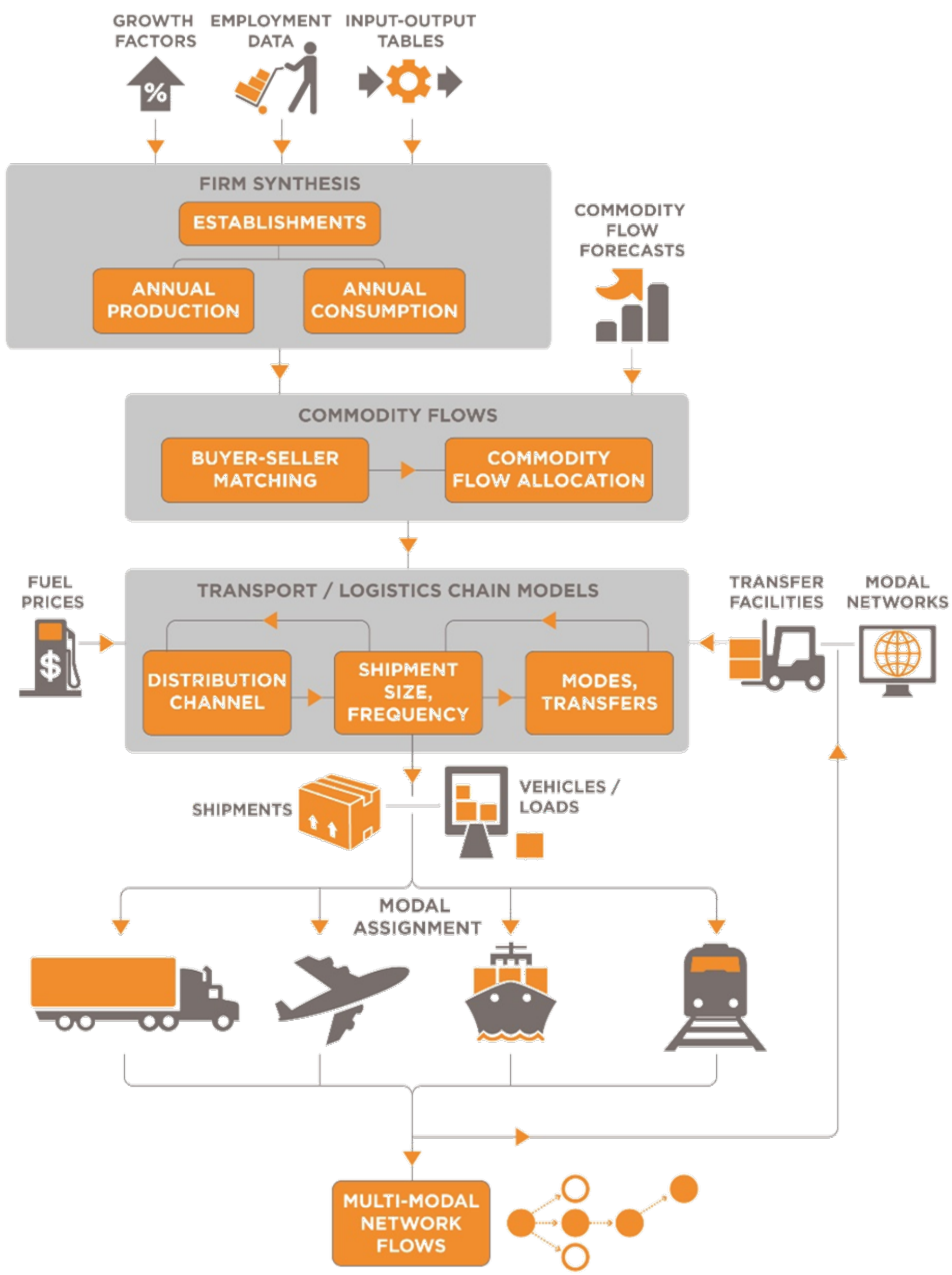

Figure 2. Behavioral Supply Chain Modeling Process.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

Firm Synthesis

In behavioral-based 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 IO 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.

Allocation of Freight Demand

Buyer-Supplier Matching

The relationships between buyers and suppliers, who ultimately become shippers and receivers of commodities, is the next core step of the behavioral-based supply chain freight models. Buyers evaluate characteristics of suppliers and transportation costs to select supplier establishments to transport goods. This process emulates the business decision to select a supplier to allocate freight demand between buyers and suppliers. The approach of buyer-supplier matching retains aggregate-level controls at the level of the Freight Analysis Framework (FAF) zone, county, or other regional geographic unit, while allowing simulation of freight movements at the subregional level by synthesizing establishments and simulating the matching of buyers and suppliers. The buyer-supplier matching process follows four steps:

1. Generate an annual production quantity as a function of establishment size (employment) for each synthetic establishment that is a producer of a commodity.

2. Generate the purchase requirements of input commodities for each synthetic establishment producing a forecasted quantity of commodity using IO accounts tables.

3. Choose a supplier located in a zone that produces that commodity for each input commodity to be purchased.

4. Allocate the commodity flow amount to buyer-supplier pairs in each zone, in proportion to their probabilities, for each FAF zone-to-zone commodity flow value.

To apply the supplier firm selection model (Figure 3), the model creates a choice set of suppliers for each buyer firm based on the commodities it requires and the corresponding NAICS code of the suppliers. A supplier firm is excluded from the choice set if no flows for the commodity being traded are observed in the FAF dataset between the relevant FAF zones. Great circle distances (GCDs) are based on the buyer and supplier FAF zones. The model calculates a score for each buyer and potential supplier pair using the attested coefficients and adding a random value for stochasticity. For each buyer firm, the model selects the supplier firm with the best (highest) score.

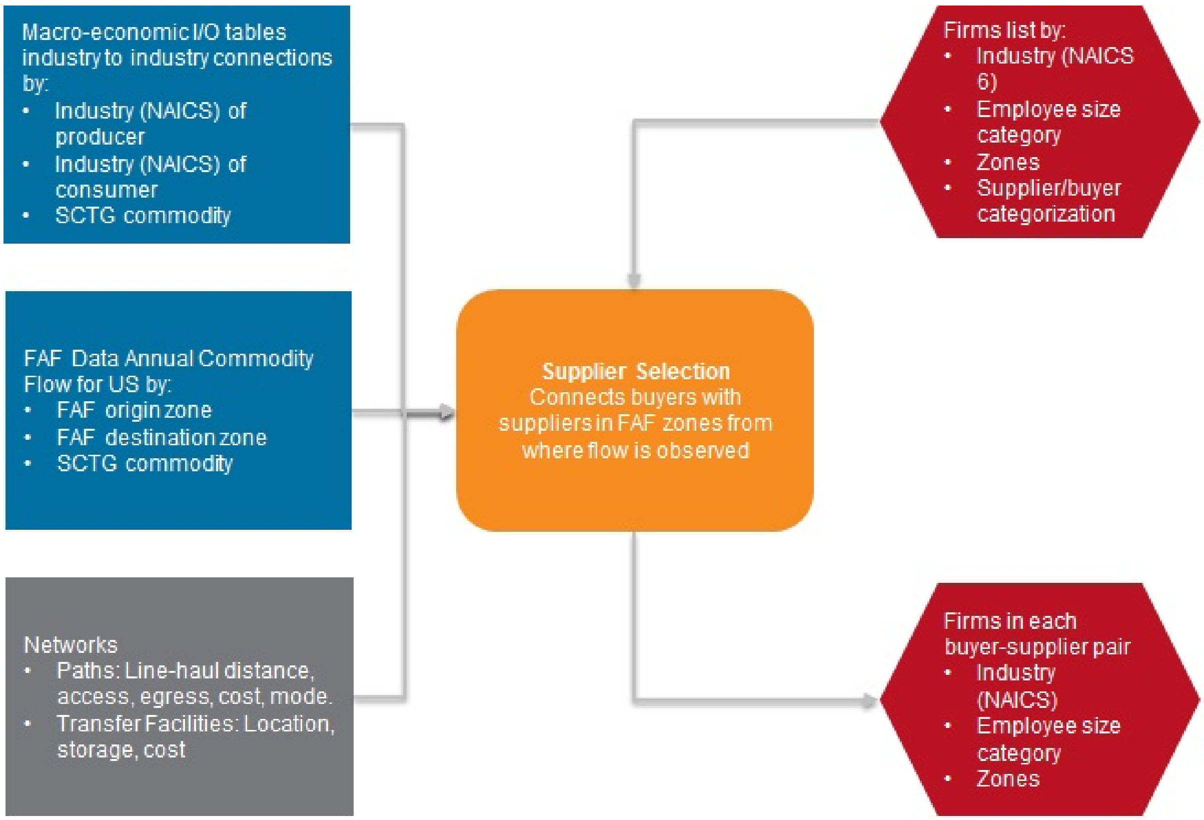

Figure 3. Supplier Firm Selection Model Process.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

Commodity Flow Allocation

The commodity flow allocation process predicts the demand in tonnage for shipments of each commodity type by each business establishment in each industry. The demand is developed to represent the goods produced by each business establishment and the goods consumed by each business establishment that leads to a freight shipment to, from, or within a region. The commodity flow allocation model's primary inputs are the FAF freight flows and the buyer-supplier pairs simulated in the supplier firm selection model. The model uses the consumption requirements by business establishments of different industries calculated in the firm synthesis model 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.

Figure 4 shows the commodity flow allocations model's inputs and outputs. Once buyer and supplier pairs have been established, the annual flow between each of the pairs is estimated, the FAF dataset is used to apportion goods demand to each buyer-supplier pair based on the size of the buyer business establishment. An estimate of consumption (of the commodity being consumed) by a buyer business establishment is calculated based on the value (in dollars) consumed per employee, which is obtained using processed IO economic tables. The values consumed per employee are calculated for each combination of supplier-buyer industry NAICS from the IO tables.

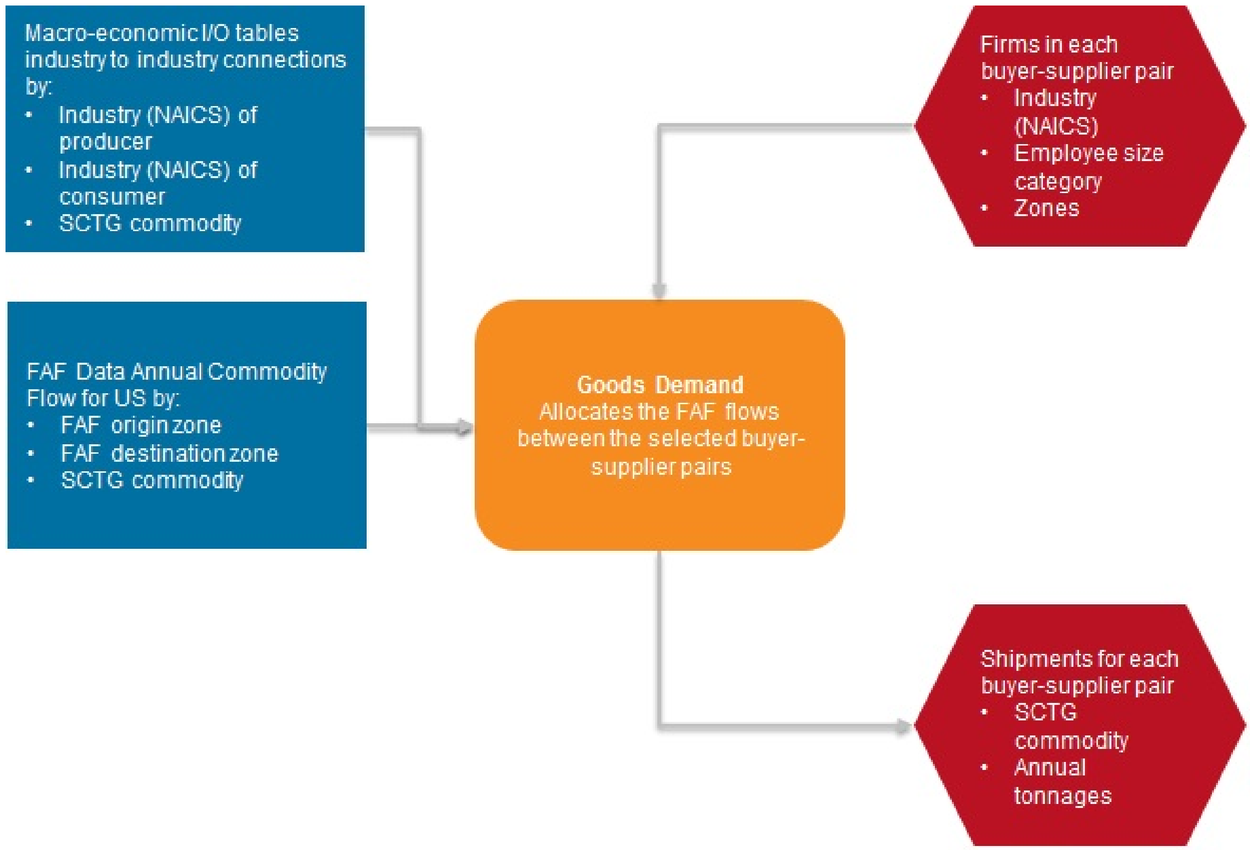

Figure 4. Commodity Flow Allocation Model.

Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

The values consumed per employee are used to calculate a consumption estimate (in dollars) for each buyer business establishment. A share of consumption for each business establishment in a particular zone is then calculated based on the consumption estimate. These shares are used to apportion freight flows for each commodity into a zone for individual buyer firms. This results in an estimate of annual goods demand between each of the buyer-supplier pairs.

Transportation Logistics Chain Models

Distribution Channels

The distribution channel model component selects the distribution 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, which is critical to freight-related business operations. The supplier firms may use their own transportation resources or send shipments to the buyer using third-party logistics (3PL) 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. The distribution channel model uses discrete choice methods to identify the unique aspects of the supply chain.

The concept of distribution channel can be simplified to obtain a reasonable sample for model estimation, as shown in Figure 5. Four alternatives for distribution channels are: direct, one-stop type, and two-stop type; and three-stop types, where stop type is a warehouse, distribution center, or consolidation center. Distribution channels that involved only one warehouse stop, or only one distribution center stop, are considered the same. Future datasets may allow for including more complex representations of distribution channels.

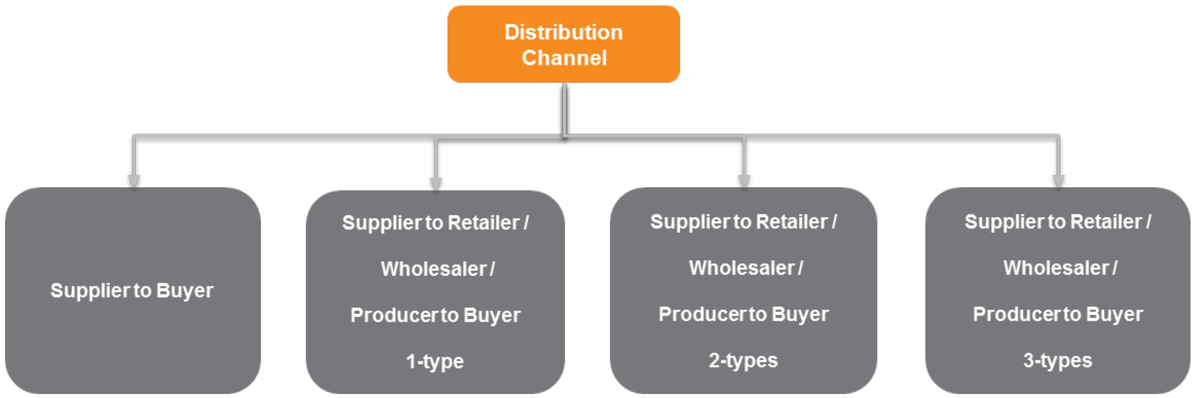

Figure 5. Distribution Channels.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

Figure 6 shows a schematic of the distribution channel model. The distribution channel model simulates shipments between all the buyer-supplier pairs based on the type of commodity. The manufactured goods model is applied for all commodities other than food. At this stage in the framework, the unit of analysis is shipments by all modes; therefore, the distribution channels are not mode specific and may be completed by a single mode or be multimodal (the process of selecting modes for movement of each shipment takes place in the mode and transfer model).

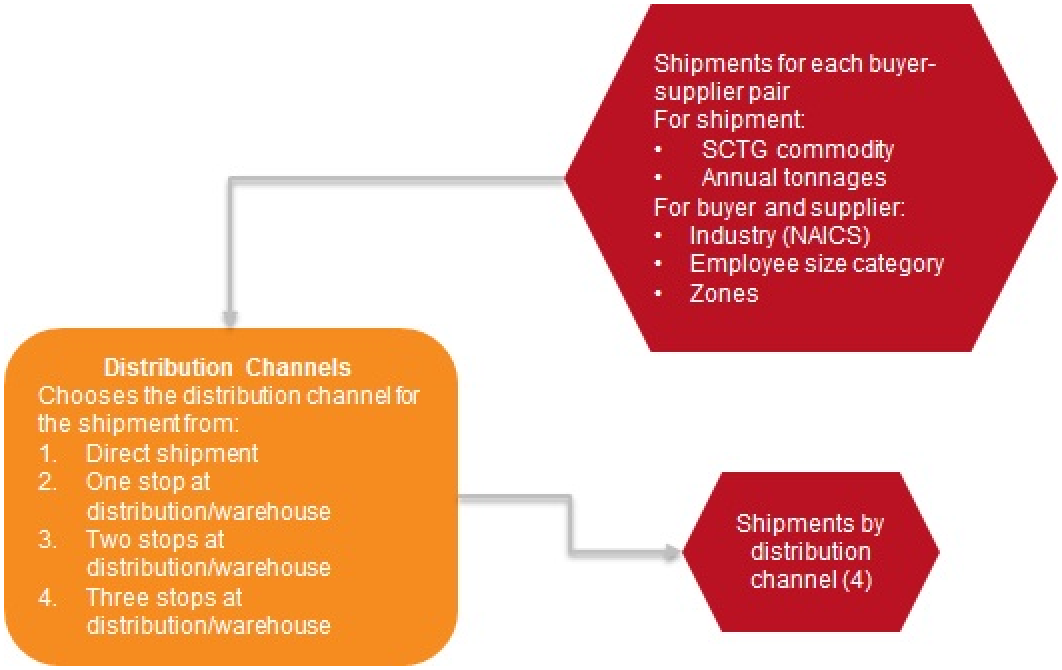

Figure 6. Distribution Channel Model Process.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

Shipment Sizes

In the shipment size model component, the annual goods flow between buyer-supplier pairs is 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. A multinomial model is estimated for choice of shipment size. A vehicle survey dataset is used for estimating the discrete choice model. The Texas commercial vehicle survey is a commonly used dataset due to its relatively high sample size. The distribution channel typically influences the choice of shipment size. Stop-level data were transformed into tour-level data and the distribution channel is assigned based on the stops made by the truck at ports, intermodal facilities, warehouses, and distribution centers. Figure 7 illustrates the shipment size and frequency model. The shipment size choice is simulated for all the buyer-supplier firm pairs using the estimated models.

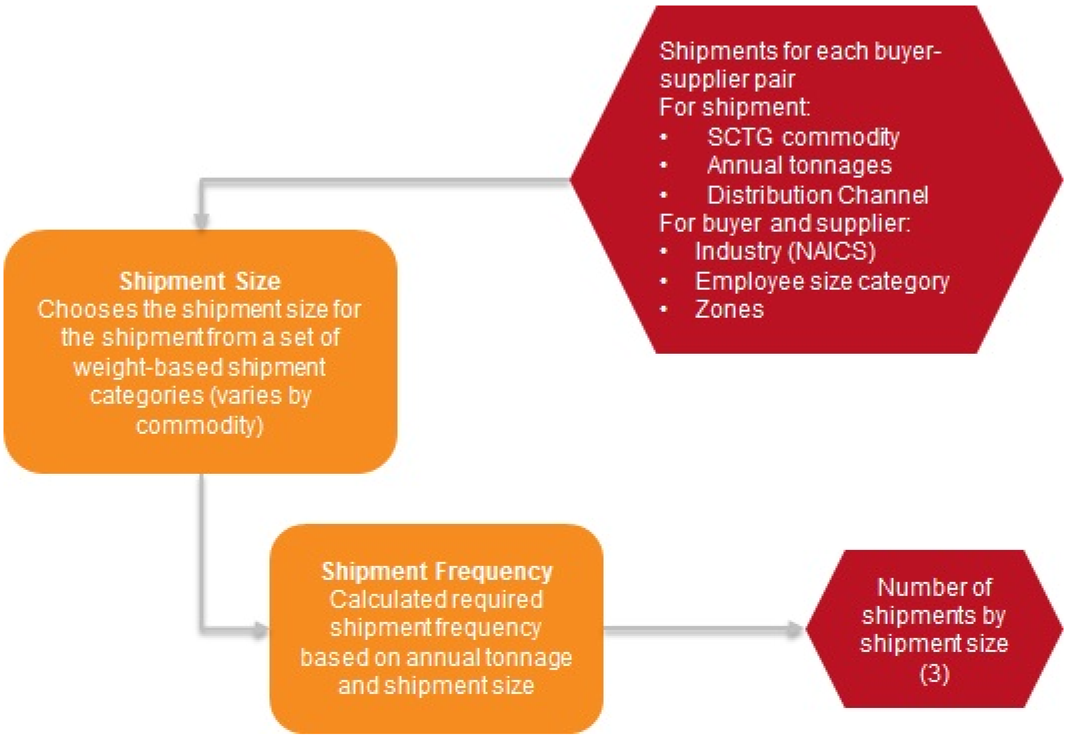

Figure 7. Shipment Size and Frequency Model Process.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

Mode and Transfers

The mode and transfer step assigns a mode for shipments transported between each buyer-supplier pair. Four primary modes (road, rail, air, and water) are typically included in the mode choice model. Pipeline can be added as a fifth mode if significant in any area. 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 two-step process selects a mode and path (from a set of feasible modes and paths)—one that would have the least annual transport and logistics cost using a two-step process:

1. Enumerate a set of feasible paths between each origin-destination pair.

2. Apply a reasonable set of parameters 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 developed by de Jong and Ben-Akiva (2007) can be used to predict the path and mode of long-haul movements of freight. The path includes identifying the location of intermodal transfer facilities, distribution centers, or warehouses are shipments are consolidated or deconsolidated. 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 GCDs between airports and between ports and international destinations. The total logistics cost that the buyer and supplier encounter is the sum of transport and inventory costs and can be itemized as shown below:

Total Logistics Costs = Transport costs + Inventory costs

Inventory Costs = Ordering + Carrying + Damage + Inventory in-Transit + Safety Inventory

Where:

- Transport cost is the annual flows multiplied by the transportation rate (cost per ton).
- Ordering is order preparation, order transmission, production setup, if appropriate.
- Carrying is cost of money, obsolescence, insurance, property taxes, and storage costs.
- Damage is orders lost or damaged.
- Inventory in transit is inventory between shipment origin and delivery location.
- Safety inventory is lost sales cost, backorder cost (demand and lead-time uncertainty).

This formulation simulates logistics decisions in a joint fashion by capturing transport and logistics costs in a single equation. This effectively reflects the real-world decision-making of freight movers by accounting for different components of costs. Figure 8 shows a schematic of the mode and transfer choice model. The buyer-supplier pairs dataset now has information on buyer firm ID, supplier firm type ID, commodity type (SCTG), annual flow in tons and dollars, distribution channel, and the shipment size. Modal skims developed are merged into the buyer-supplier pairs dataset.

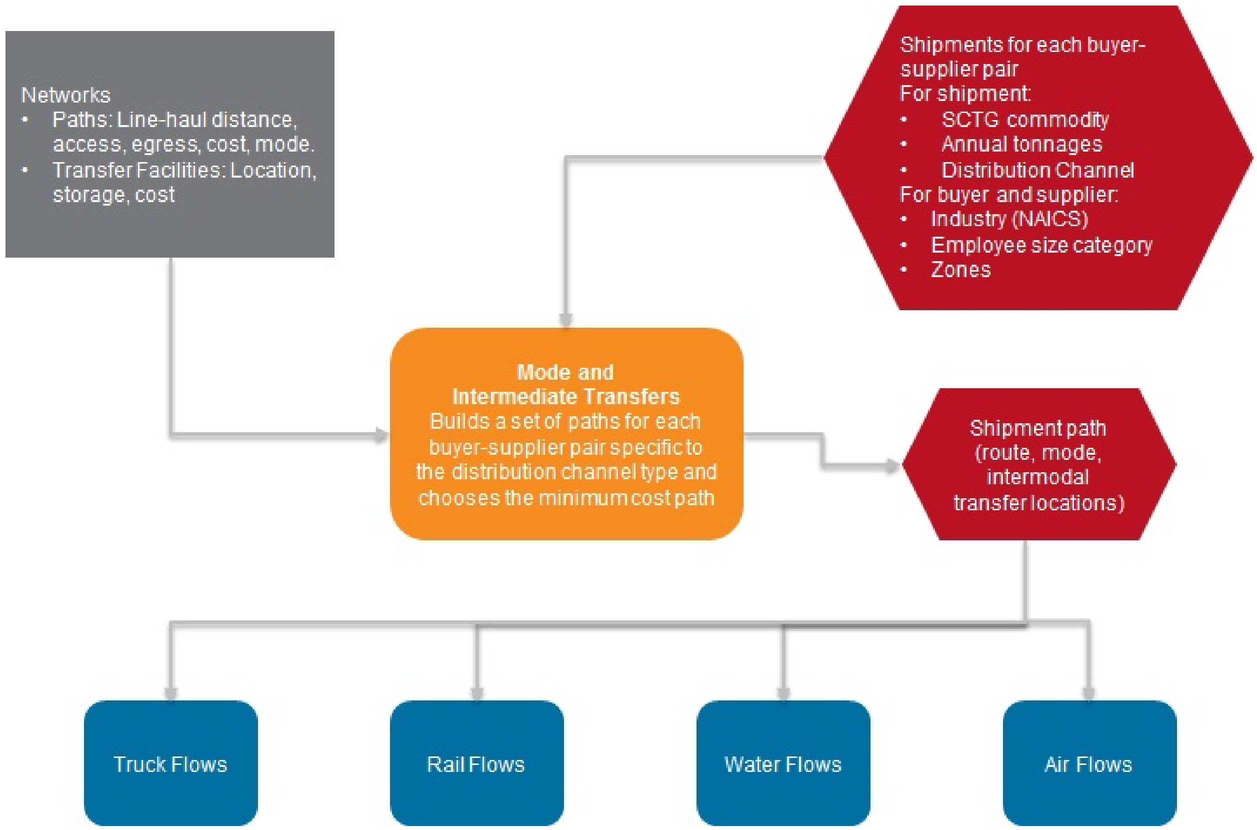

Figure 8. Mode and Intermediate Transfer Model Process.

Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

TOUR-BASED TRUCK MODELS

The behavioral-based supply chain freight model can be integrated with a regional truck touring model, which is a sequence of models that takes shipments from their last transfer point to their final delivery point. The integrated modeling system connects the national supply chain models with the regional truck touring models. The final transfer point is the last point at which the shipment is handled before delivery (i.e., a warehouse, distribution center, or consolidation center for shipments with a more complex supply chain or the supplier for a direct shipment). It performs the same function in reverse for shipments at the pick-up end, where shipments are taken from the supplier to distances as far as the first transfer point. For shipments that include transfers, the tour-based truck model accounts for the arrangement of delivery and pick-up activity of shipments into truck tours.

A commercial services touring model can be developed to provide a comprehensive representation of all trucks. This model has the same structure and features of the regional truck touring model, but demand is generated from businesses and households in the region rather than from goods movement. These commercial services include utilities, business, and personal services. Delivery of goods to residences by parcel delivery are typically included in the services touring model.

The model produces 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, as shown in Figure 9:

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 that 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 become part of the regional travel demand modeling system.

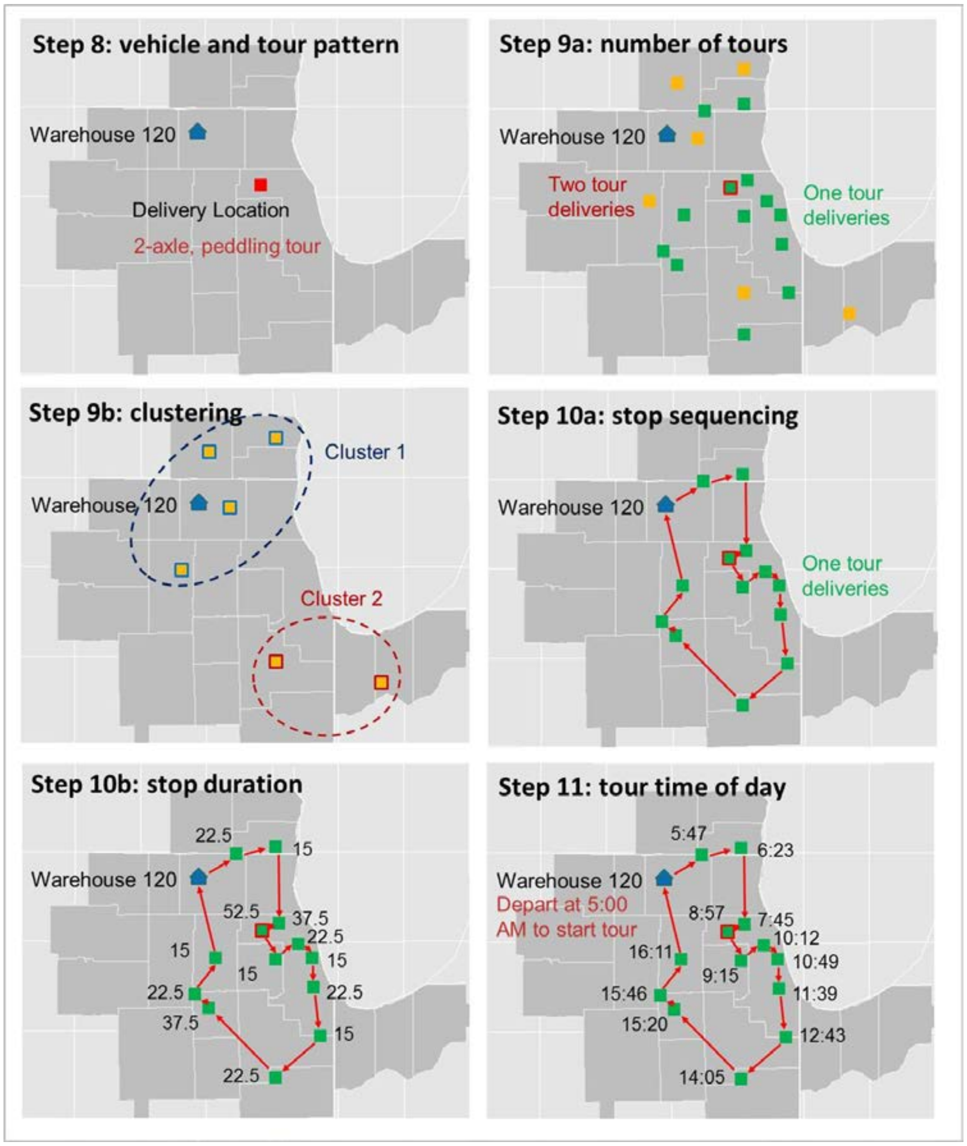

Figure 9. Truck-Touring Model Steps.
Source: (Smith, 2013)

MODEL APPLICATIONS

Behavioral-based supply chain freight models can be used for myriad policy applications. These are dependent upon the specific components that are included and can be categorized into two main types of modeling systems: 1) national supply chain models; and 2) regional truck touring models. The national supply chain models include the firm synthesis, allocation of freight demand, and transportation logistics chain components and can support the following policy analyses:

- **Modal alternatives**. No direct competition exists between air, rail, water, and truck for freight movements, and any infrastructure investments being considered should be evaluated in the context of this competition. These alternatives are evaluated nationally and—to a lesser degree—internationally to capture any impacts in a State or region.

- **Pricing**. Many aspects of pricing can and should affect statewide freight forecasts. Pricing can be a strategy to manage demand or raise revenues (e.g., toll roads, gas taxes, mileage fees). Pricing affects the travel decisions of drivers, shippers, carriers, and 3PL establishments differently.
- **Economics**. Policies to improve economic conditions will affect freight and goods movement. Economic conditions could be tested by adjusting these inputs to understand the effects on freight mobility of a greater demand for goods. Higher employment in a State will lead to additional production and consumption of commodities, which can be represented by alternative employment and commodity flow inputs. Policies such as freight tolling and truck restrictions can be analyzed to understand the effects on freight.
- **Environmental**. Policies to reduce transportation-related emissions can have effects on freight and goods movement. An increase in the gas tax will influence gas consumption and potentially reduce vehicle miles traveled. Carbon taxes may also affect the cost of freight transport. The Environmental Protection Agency may change fuel standards for trucks, which would affect the transport cost for trucks.
- **Safety**. Policies such as driver hours-of-service regulations and technologies to reduce accidents for hazardous materials transport will affect decisions on the cost to transport goods and on what modes to use for certain goods.
- **Airport, Seaport, or Rail Planning**. Policies made by airports, seaports, or rail operators regarding new capacity, intermodal terminals, or environmental effects can be evaluated.

Regional truck touring models can address regional impacts for the following policy analyses:

- **Policies**. Regional policies such as taxes, tolls, or local delivery times will result in different freight mobility in different cities. Truck route restrictions and truck size and weight limits can also affect route decisions.
- **Environmental.** Policies to reduce regional emissions impacts can be evaluated in a similar manner as the national supply chain models (see preceding description).
- **Pricing**. Regional pricing options can be evaluated in a similar manner as the national supply chain models (see preceding description).
- **Airport, Seaport, or Rail Planning**. Regional infrastructure for ground access to ports or rail stations can be evaluated.

The project team identified several model applications in the case studies, including the following:

- Inform infrastructure investment decisions.
- Evaluate congestion on highways.
- Test the effectiveness of transportation policies on mobility and the economy. This will include policies such as freight tolling and truck restrictions. This will also include evaluating economic scenarios.

- Produce multimodal system performance measures for freight.
- Evaluate the effects of private sector decisions on the transportation system.
- Provide regional agencies with intercity freight travel information for regional planning purposes.
- Evaluate freight mobility alternatives for long-range plan development and corridor analyses.
- Consider truck emissions in federal transportation conformity determination.
- Evaluate accessibility to manufacturing and industrial centers.
- Assess emergency management and evacuation procedures.

CHAPTER 3. FREIGHT MODEL DATA AND RESOURCES

Acquiring the data and finding the resources required to support a behavioral supply chain model is often challenging, given the privacy and confidentiality issues surrounding supply chain data. This chapter describes the data required to support such a model. It also describes the data and resources assessment for model development.

COMMON DATASETS

Many data sources exist for estimating, calibrating, validating, and forecasting a freight modeling system. Advanced freight travel demand modeling in the United States often uses publicly available data sources to model freight movements. Publicly available data (at no cost) will require some level of effort to process and clean before it is available for use. This section describes common data sources used by public agencies to build advanced freight travel demand models.

Commodity Flow Data

Many models rely on Freight Analysis Framework (FAF) data as input. FAF is a publicly available commodity flow dataset used in supply chain models. The FAF integrates data from several 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 (FAF4) provides estimates for tonnage, value, and domestic ton-miles by region of origin and destination, commodity type, and mode for 2015 (the most recent year) and forecasts through 2045. Also included are state-to-state flows, summary statistics, and flows by truck assigned to the highway network for 2012 and 2040. FAF flows are also used as control totals for freight moving into and out of the region being modeled and for projected freight movements to exterior zones outside of the modeling region.

The structure of the FAF consists of 132 CFS regions (or FAF zones) divided in the following subsets: metropolitan area determined regions; regions representing a State’s territory outside metropolitan regions; and regions identified as entire states, within which no FAF metropolitan regions exist. Metropolitan regions do not cross State boundaries. Eight international trade regions model U.S. exports and imports. Figure 10 and Figure 11 show FAF domestic and international zones.

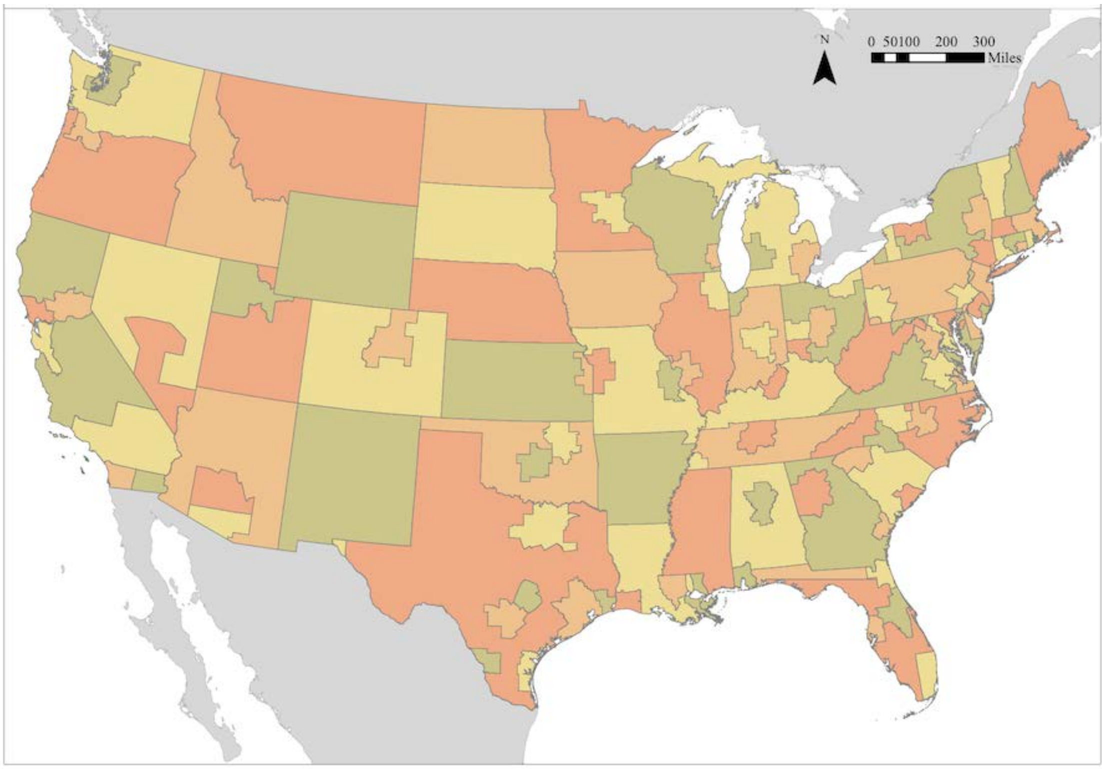

Figure 10. FAF Domestic Zones.
Source: (Federal Highway Administration, 2017)
Note that Hawaii and Alaska are included as FAF zones, but are not shown on this map.

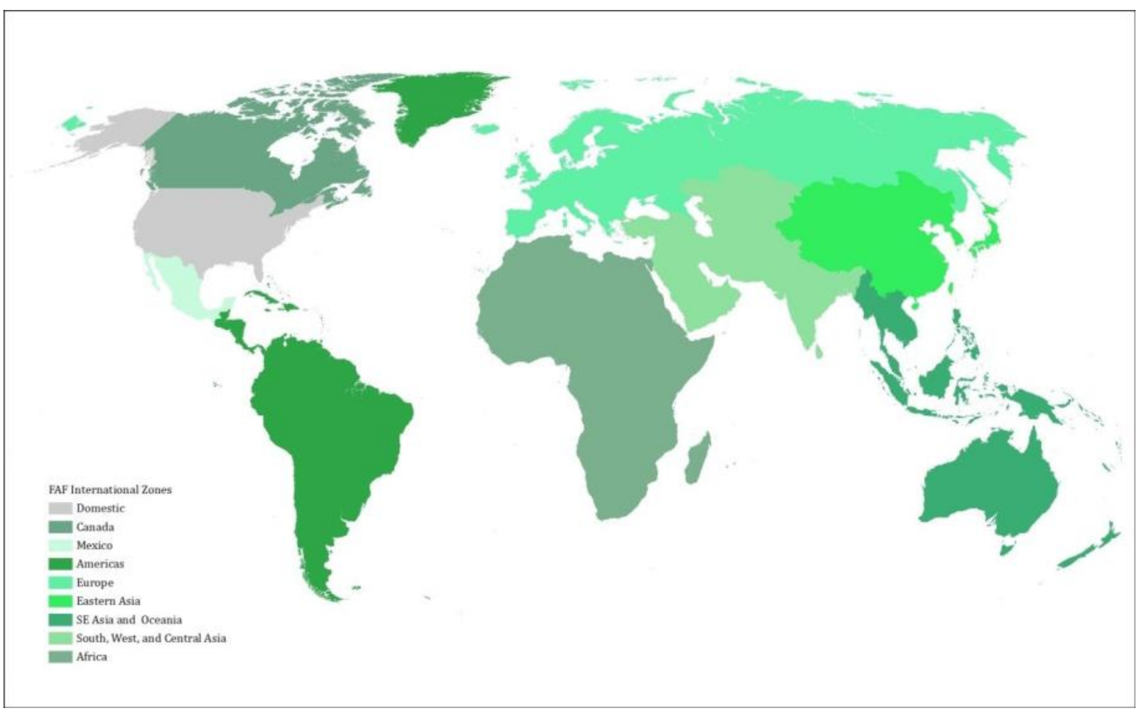

Figure 11. FAF International Zones.
Source: (Federal Highway Administration, 2017)

The FAF4 has several data products, including a regional database and network database with highway flow assignment. The principal dimensions to the flow matrix are origin, destination, commodity, and mode. The 2012 freight flow matrix is used as the starting point for future-year forecasts, projecting volumes out to 2045. The FAF4 makes extensive use of the CFS data, but also relies on other data sources. FAF4 reports annual tonnage and dollar-valued freight flows using the 43, two-digit Standard Classification of Transported Goods (SCTG) commodity classes used by the 2012 CFS. FAF4 modes include truck, rail, water, air, multiple models, pipeline, and unknown.

Employment and Establishment Data

County Business Patterns (CBP) data contains the number of establishments in each size category, defined by industry and number of employees for each county in the United States. Industry is defined based on the North American Industrial Classification System (NAICS) six-digit classifications. The dataset is an annual series that provides county-level economic data, by industry type. This series includes the number of establishments, employment, and annual payroll. CBP data have been used to develop advanced freight models. The data are used to synthesize establishments in the supply chain model before allocating to analysis zones and selecting supplier/buyer pairs. CBP data does not contain foreign employment data and foreign firms need to be represented in the model. The primary objective of including foreign establishments in the model is to ensure that international flows between the region and foreign countries can be allocated to either buyers or supplier firms at the foreign country end.

Another publicly available data is the Longitudinal Employer-Household Dynamics (LEHD) which is a national longitudinal job frame that combines data from State and federal sources to create a linked employer-employee dataset. These data are collated by the U.S. Census Bureau and cover approximately 90% of employed persons. LEHD data can be used to disaggregate the business locations for the regions of interest from the counties in the CBP data to the more detailed Traffic Analysis Zones (TAZs) used in the model TAZ system.

LEHD and CBP data provide summaries of establishment-based employment, aggregated by U.S. county and organized by NAICS industry codes and establishment-size groupings. Like the commercial datasets, CBP and LEHD do not cover agriculture, construction, and public administration. Due to this lack of coverage, State and metropolitan transportation planning agencies in the United States typically supplement these data using State or local employment estimates, filling in missing sectoral employment and reconciling known local discrepancies.

For instance, agriculture data on farms—by size and sales—can be derived from U.S. Department of Agriculture (USDA) Census of Agriculture data to provide supplemental data for understanding agricultural production locations. Agricultural establishments and employment are not well represented in CBP and LEHD data, and synthetic farms can be generated from other available data sources. Various tables from the USDA Census of Agriculture can be used to develop number of farms by county and NAICS industry codes to append to the CBP table to cover the missing agricultural industry establishment data. Employment on military bases is also not collected as part of the Economic Census, but it can be obtained on a case-by-case basis.

Industry Economic Accounts Data

The U.S. Bureau of Economic Analysis (BEA) produces Input-Output (IO) "Make" and "Use" tables that report the value of goods consumed by each buyer industry. This can be used to identify the most important consumed commodities (by dollar value) and their associated supplier industries. These tables show production relationships among nearly 400 industries and commodities. Table 2 is an example of the information content of a "Use" table. These tables can also be used to spatially apportion commodity flows by commodity type and industry.

DATA AND RESOURCE ASSESSMENT

There are multiple potential data sources used by agencies to estimate, calibrate, and validate the forecasting of a freight modeling system. Table 3 summarizes primary data sources used for behavioral supply chain freight models and includes details on each data source. The table does not include observed data (e.g., truck counts, Weigh-in-Motion [WIM] data) or local survey data available from local agencies.

Table 2. Example IO Accounts "USE" Table (Sample Data View).

Commodity	Commodity Description	Industry	Industry Description	Producer Value	Purchaser Value
1111A0	Oilseed farming	1111A0	Oilseed farming	1025.2	1137.6
325320	Agricultural chemical manufacturing	1111A0	Oilseed farming	508.4	702.9
324110	Petroleum refineries	1111A0	Oilseed farming	413.4	462.4
1111B0	Grain farming	1111A0	Oilseed farming	320.4	320.4
325310	Fertilizer manufacturing	1111A0	Oilseed farming	269.8	316.6
212100	Coal mining	212100	Coal mining	1199.4	1970.7
333120	Construction machinery manufacturing	212100	Coal mining	628.7	760.7

Source: (United States Bureau of Economic Analysis, 2017)

Table 3. Primary Data Sources by Modeling Needs and Availability.

Data Source	Availability (latest available)	Spatial	Temporal	Modes	Industry Detail	Commodity Code	Model Inputs	For Model Estimation	For Model Calibration	For Model Validation
CBP	Public, 2014	County	Annual	N/A	Two to Six-digit NAICS codes	N/A	✓	✓	✓	✓
BEA IO Accounts	Public, 2015[1]	National	Annual	N/A	Two to six-digit NAICS codes	N/A	✓	✓		
FAF	Public, 2015	FAF Zone	Annual[2]	All modes	N/A	Two-digit SCTG Commodities	✓	✓	✓	✓
CFS	Public, 2012	BEA Zone	Every five years	All modes	N/A	Two-digit SCTG Commodities		✓	✓	✓
Vehicle Inventory and Use Survey (VIUS)	Public, 2002	State	Every five years	Truck	N/A	Two-digit VIUS Commodities		✓	✓	
TRANSEARCH	Private, 2015	County	Annual	All modes	N/A	Four-digit Standard Transportation Commodity Code (STCC)			✓	✓

[1] The latest detailed (by six-digit NAICS) Input-Output table available is for 2007.
[2] Major updates to the FAF data are performed using the CFS data (every five years) and the latest is available for 2012.

Data Source	Availability (latest available)	Spatial	Temporal	Modes	Industry Detail	Commodity Code	Model Inputs	For Model Estimation	For Model Calibration	For Model Validation
						Commodities				
Surface Transportation Board Waybill	Public, 2014	BEA Zones	Annual	Rail	N/A	Four-digit STCC Commodities			✓	✓
T-100	Public, 2016[3]	Airport	Annual	Air	N/A	N/A			✓	✓
Port Import/ Export Reporting Service (PIERS)	Private, 2015	Port	Annual	Water	N/A	Two-digit Harmonized System Commodities			✓	✓
ATRI	Private, 2017	Truck O-D	Daily	Truck	N/A	N/A			✓	✓
National Transportation Atlas Database (NTAD)	Public, 2015	Facility Location	Annual	N/A	N/A	N/A	✓			

[3] Private version of the waybill data includes more coverage and is often included in the TRANSEARCH data.

Data Available for Model Inputs

Behavioral supply chain freight models often use the following six types of model input data:

- **Zone systems** for behavioral supply chain models are tiered so that the model can operate at a national scale (with limited international zones), a regional or statewide scale, and at a Transportation Analysis Zone scale. The Transportation Analysis Zone system represents the study area of interest, the regional or statewide scale represents less detail in adjacent States (often counties), and the national scale represents states or metropolitan regions in the remainder of the United States.
- **Network systems** represent multimodal networks supporting the movement of goods. Typically, modal networks include highway and rail; more advanced models also include water and air. Pipeline networks are being developed by Resource Systems Group as part of the development of a behavioral national freight supply chain model for Federal Highway Administration (FHWA) and may be available in the future for others to include. National Transportation Atlas Database is a national source of modal network data and is typically combined with local network data sources.
- **Employment data** are developed at the Transportation Analysis Zone level using locally sourced employment datasets, often derived from the quarterly census of employment and wages. In addition, the County Business Pattern offers marginal distributions of employment by size and industry at the county level.
- **Transfer facilities** include intermodal terminals, warehouses, and distribution and consolidation centers. Data for transfer facilities location can be found in the National Transportation Atlas Database merged with data on employment from the Transportation Analysis Zone-level employment dataset.
- **Economic data** represent the value of commodities exchanged between industries, also called IO Make and Use Tables. Economic growth rates are also required for forecast models.
- **Freight flows** are developed from the Commodity Flow Survey and products like the FAF provide a useful processed and cleaned dataset of freight flows sorted by mode at the national scale. These data must first be disaggregated to the local level. Freight flows are a primary input to most of the behavioral supply chain models—except in Chicago, Illinois, where the procurement market model produces freight flows instead of allocating freight flows to a smaller geography.
- **Freight Surveys** can include commodity flow surveys, establishment surveys, truck diary surveys, vehicle use surveys to estimate parameters for mode, shipment sizes, distribution channels and buyer-supplier matching.
- **Truck Global Positioning System (Global Positioning System) Data** is used to estimate parameters for truck time of day models and vehicle origin-destination patterns.

Freight flows have been typically included as an input in the models, since there are datasets (i.e., Freight Analysis Framework) that are publicly available. The Freight Analysis Framework and other freight flow datasets provide a version of the future based on a specific economic forecast. Including a procurement market model that produces freight flow forecasts based on economic and infrastructure forecasts in the freight model introduces more transparency and sensitivity into the freight forecasting process.

Availability of Data for Estimating Model Parameters

National Data

Data for estimating behavioral supply chain freight model parameters requires disaggregate data, which is difficult to obtain. Data from national, State, or regional surveys is difficult and costly to collect. Thus, these data are collected infrequently or with small sample sizes. National surveys commonly used for model estimation by agencies include the following:

- CFS[1] is collected every five years (1997, 2002, 2007, 2012) and includes a large sample size. Unfortunately, these data are not available in disaggregate form and are not useful for estimating model parameters (the 2012 CFS Public Use Microdata [PUM][2] has been explored as an option for disaggregated data, but there are issues with data suppression).
- The Freight Activity Microsimulation Estimator survey[3] (2009–11, in three waves) is an establishment survey with a small sample, but it contains information on transfer facilities, mode, and commodity that have supported estimation of distribution channel models.
- The Vehicle Inventory and Use Survey[4] was last collected in 2002, but is still being used as the best source for truck payload factors.

Establishment Surveys

Several states and regional transportation agencies have conducted establishment surveys, but only the establishment surveys that are combined with commercial vehicle diary surveys can be used effectively to estimate model parameters for behavioral supply chain models. The following agencies contacted as part of this synthesis have used these types of surveys:

- The Ohio statewide survey (2004).
- Five regional surveys conducted in Texas (2001–2006).
- The Maricopa Association of Governments (MAG) regional survey (2016).
- The Portland Metro regional survey (2016).

Both the MAG and Portland surveys employed smartphone mobile applications to collect data, which provided more detailed and accurate truck travel data. Challenges around recruitment of establishments and drivers to participate in these surveys continue, which is the primary reason for high survey costs.

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[1] The CFS Data (enumerated web address: https://www.census.gov/econ/cfs/).
[2] The CFS PUM Data (enumerated web address: https://www.census.gov/econ/cfs/pums.html).
[3] FAME Survey Project (enumerated web address: https://apps.ict.illinois.edu/projects/getfile.asp?id=3074).
[4] Vehicle Inventory and Use Survey - Discontinued (enumerated web address: https://www.census.gov/svsd/www/vius/2002.html).

GPS Data

Passively collected GPS data offer a partial solution to the challenge of collecting data on commercial vehicles. GPS data typically includes data on travel time, origin-destination, and time of travel. Private vendors (e.g., ATRI, Streetlight) offer large samples of GPS data with these data. Also, private vendors (i.e., EROADS, INRIX) provide additional attributes on commercial vehicle travel, such as truck type, commodity or industry group, and weight. Private firms also collect their own data to monitor fleets, and transportation agencies can request these data. Many private firms will not share their proprietary data, but sharing these data offers a low-cost solution to the commercial vehicle data challenges; these data also contain additional attributes over the larger samples provided by GPS data vendors.

Data for Model Calibration and Validation

Travel demand modeling best practice includes selecting different data sources for model calibration and validation than those used in model estimation. This practice has not always been possible given limited data availability for the development of behavioral supply chain freight models. Available data sources identified for model calibration and validation typically fall into five categories:

- **Freight Surveys** are used for shipment sizes, distribution channels and freight flows. These are typically collected locally by the agency developing the behavioral supply chain model, but could also be conducted as national surveys.
- **Freight Flow Data** are used to compare the distribution of shipment sizes by commodity and modal freight flows.
- **Truck GPS Data** are used to compare truck trip distributions, time of day, and volumes and is available through private vendors for a specific State or region.
- **Weight Data** are used to adjust vehicle loading factors used to convert shipment tonnages to truck trips.
- **Modal Volumes** are used to compare observed and modeled volumes. These are used to develop calibration weights for the mode and transfers model and the estimation of import and export volumes for each port.

Freight surveys, freight flow data, GPS, and weight data are all potential model estimation data sources. If multiple datasets are available, then the best practice is to select one dataset of a single type for model estimation and a second dataset for model calibration and validation.

CHAPTER 4. AGENCY EXPERIENCES WITH BEHAVIORAL/AGENT-BASED SUPPLY CHAIN MODELS

This chapter details the comprehensive review of the state-of-the-practice models. The models reviewed are summarized along 12 dimensions related to methodology and data. The information in this chapter is based on the information collected and reviewed from the public agencies identified in Chapter 1. Models are presented in order of development date, from earliest to most recent.

CHICAGO METROPOLITAN AGENCY FOR PLANNING

Methodology

The Chicago Metropolitan Agency for Planning (CMAP) has been incrementally building a regional freight model since 2010. CMAP first developed the firm synthesis, supplier selection, and mode choice elements of its freight modeling system (Cambridge Systematics, 2011). CMAP then added supply chain and logistics elements and truck-touring models (RSG, University of Illinois at Chicago and John Bowman, 2012). Finally, CMAP (RSG, 2017) developed an extension to the mesoscale model, a modeling tool for forecasting future freight flows under different sets of investment, policy, and macroeconomic scenarios. The mesoscale model extension can help analyze industries and answer questions regarding how such industries might affect the freight-dependent business community.

Supply Chain Modeling Needs

CMAP developed a freight forecasting model for policy and planning sensitivity analysis to systematically vary forecasts to reflect potential changes in macroeconomic conditions (e.g., foreign trade levels, price of crude oil); large-scale infrastructure changes (e.g., port expansions, new intermodal terminals); technological shifts in logistics and supply chain practices (e.g., near-sourcing, outsourcing, productivity enhancements); and other assumptions and scenario inputs related to the economic competitiveness of the Chicago region and its infrastructure investments. CMAP also intends to use their freight forecasting model to evaluate performance of local freight facilities (e.g., transfer terminals, roads, rail, water, and air cargo infrastructure). The Chicago region's long-range comprehensive plan[1] calls for the development of robust modeling tools to address the local and regional effects of freight transportation-based changes in the economy and freight delivery systems. CMAP desires an analysis tool that explains the economic choices made for goods movement across multiple modes and commodities, and that provides a picture of the region's role in the national freight economy. Once the updated model (currently under development) is ready to use, initial efforts will focus on providing an understanding of how freight currently moves throughout the region. As a start, CMAP freight planning staff may be interested in evaluating the regional impacts of freight policies such as overnight delivery ordinances or the expansion of logistics terminals within the region.

[1] Chicago region's long-range comprehensive plan (enumerated web address: http://www.cmap.illinois.gov/about/2040).

Model Structure, Component Interactions, and Segmentation

The national-scale portion of the CMAP freight model addresses how establishments that buy goods select suppliers and how suppliers ship goods to their buyers. Figure 12 presents the CMAP national-scale model structure process.

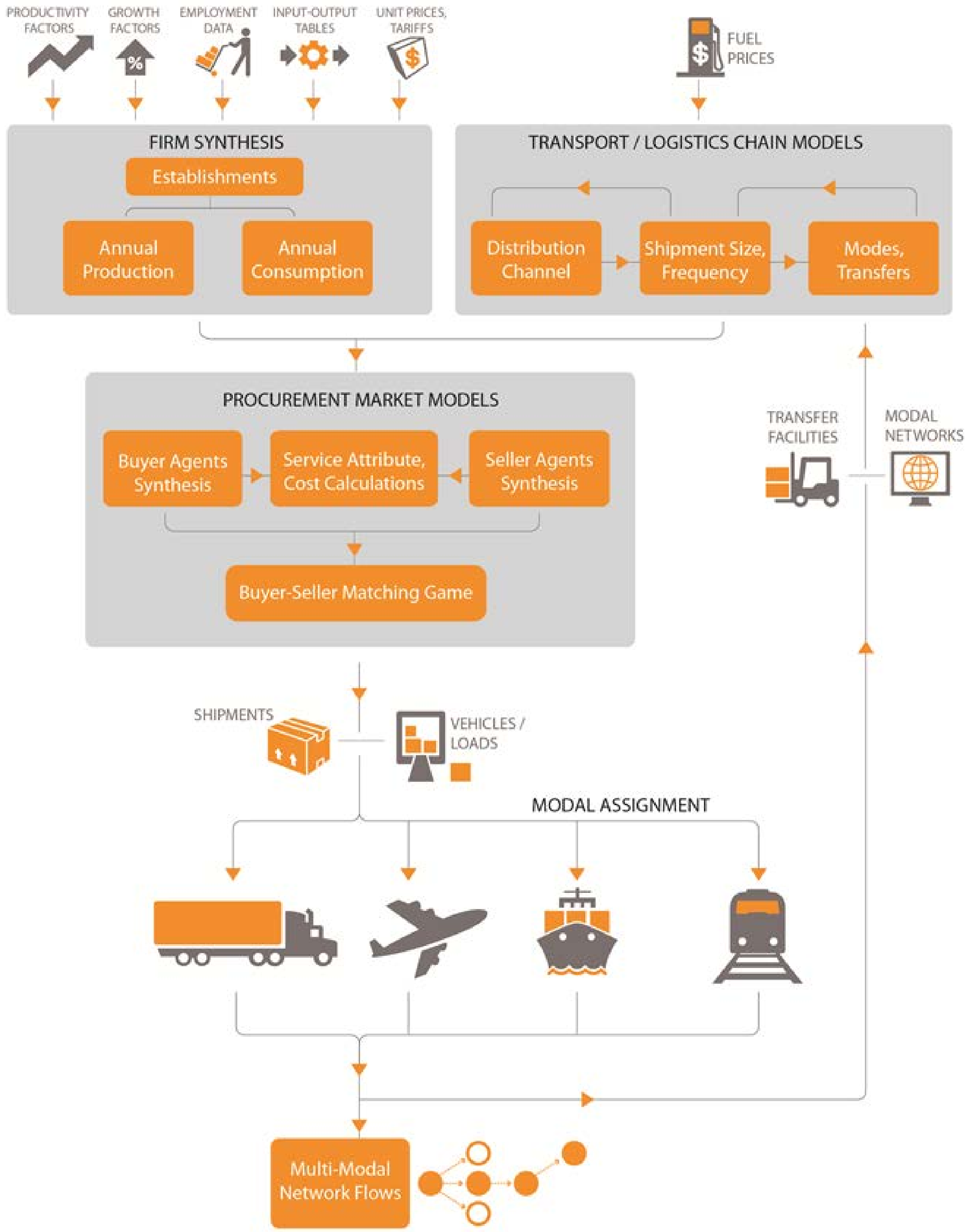

Figure 12. CMAP National-Scale Supply Chain Model Process.
Source: (RSG, 2017)

Initially, the model synthesizes establishments across the United States by industry and size category. The model then determines the complexity of the distribution channel used in the supply chain. Multinomial logit choice models determine the supply chain type based on buyer-supplier pair characteristics and industry characteristics. The four chosen distribution channels represent complex supply chains rather than a single supply chain.

The national-scale models identify the shipment size, frequency, and mode of shipments based on travel time and cost and the characteristics of the shipments and distribution channels.

CMAP uses a flexible agent-based computational economics approach for modeling the evolution of regional supply chains, as influenced by key economic drivers. The model starts by synthesizing U.S. establishments by industry classification and size, locating them spatially, and deriving annual production and consumption requirements from existing commodity flow relationships between producing and consuming sectors of the national economy, as represented in U.S. Bureau of Economic Analysis benchmark IO accounts data. The model system also synthesizes agents representing establishments in countries and industries that currently trade with the United States.

For each commodity market, an iterative procurement market game (PMG) is played. The PMG involves a pool of buyers who attempt to procure inputs from a pool of sellers in the market. As an input to the PMG, the transport-logistics chain models simulate the choice of distribution channels, shipment sizes, and modes for each prospective buyer-supplier pair, thereby enabling the calculation of logistics costs and shipping times. Buyers consider shipping times, unit costs (transport and nontransport), and risk minimization (e.g., supply chain disruption). Sellers, who are capacity constrained, evaluate whether to trade with a buyer in the face of other, potentially more lucrative offers. Through repeated bilateral games, agents form preferences for specific trading partners based on past interactions and may adjust their tolerances for risk based on market constraints.

The final round of the game (after a user-specified number of iterations) indicates which agents established trading relationships and the quantities of commodities bought and sold, producing a set of spatially distributed freight flows between establishments located in freight analysis zones. In most markets, buyers will far outnumber sellers; however, buyers will likely purchase commodities from multiple sellers, either for risk-minimization reasons or limited individual seller capacity. Because foreign buyers and sellers are included in the procurement market, the model also predicts import and export flows.

The regional-scale truck-touring models were developed as integrated elements of the freight modeling system, with direct inputs from the national-scale supply chain models. The model produces trip lists for all the freight delivery trucks in the region that can then be assigned to a transportation network. The truck-touring model components predict the elements of the pick-up and delivery system within the Chicago region through several modeling components, as shown in Figure 13:

- **Vehicle and tour pattern choice**. Predicts the joint choice of whether a shipment will be delivered on a direct- or a multistop tour and the size of the vehicle that will make the delivery.

- **Number of tours and stops**. Predicts the number of multistop tours required to complete all deliveries and estimates the number of shipments that the same truck can deliver.
- **Stop sequence and duration**. Sequences the stops in a reasonably efficient (but not necessarily the shortest-path) sequence. Predicts the amount of time taken at each stop based on the size and commodity of the shipment.
- **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.

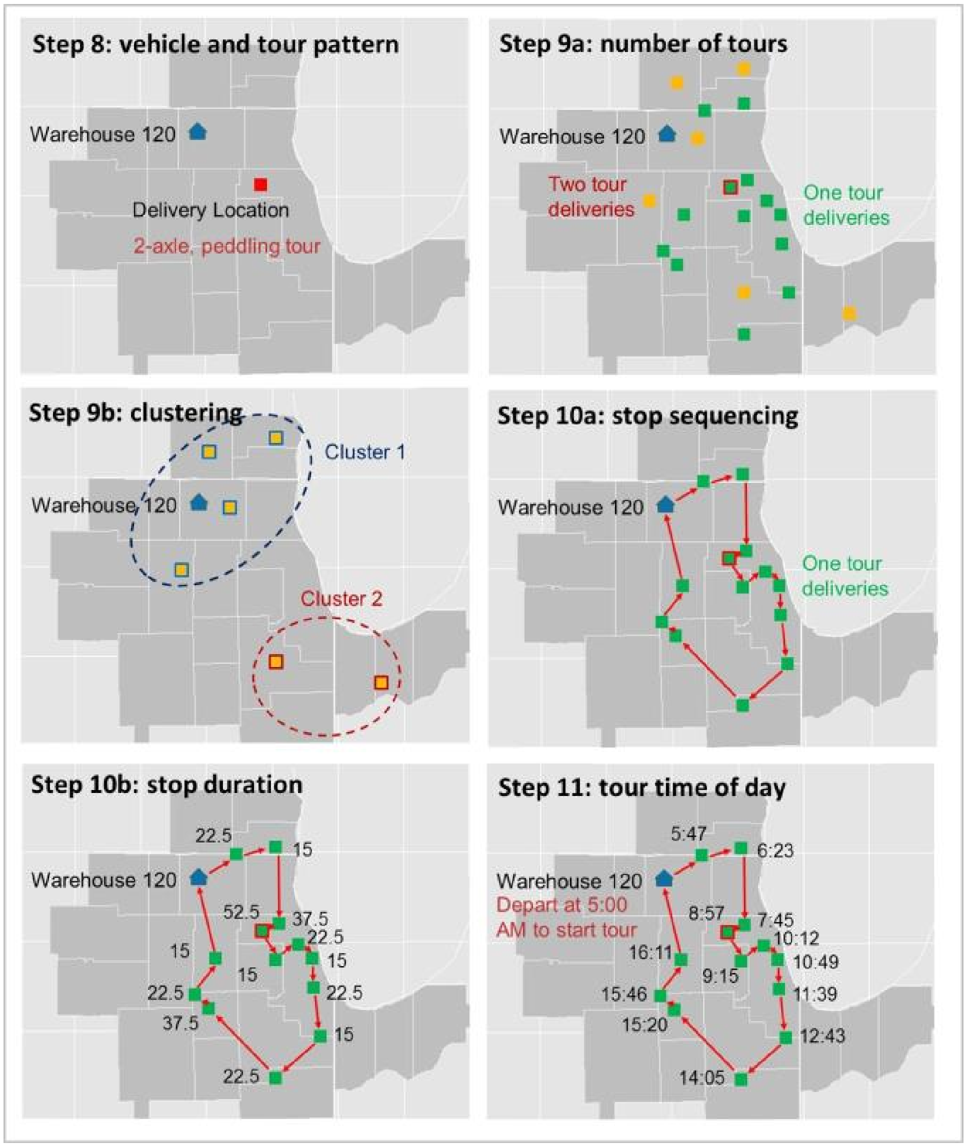

Figure 13. CMAP Regional-Scale Truck-Touring Model Process.
Source: (Smith, 2013)

The model simulates the evolution of globally connected supply chain relationships in the Chicago region and how these trading relationships translate to regional freight flows defined by industry, commodity, size, and mode. The buyer-supplier matching component operates as a processing kernel within the larger mesoscale freight model to simulate the evolution of supply chain relationships, rather than allocating a fixed freight demand. The regional tour-based truck model component evaluates the performance of existing and future regional freight facilities.

Market Segmentation (Industry, Commodity, Mode, Vehicle Type, Temporal, Activity Type)

The CMAP freight model employs several types of market segmentation depending on the unit of analysis of each model component:

- Represents 20 industry categories and seven establishment sizes in employment data, resulting in 140 classifications of establishments, by size.
- Represents 43 Standard Classification of Transported Goods (SCTG) commodity groups.
- Includes four primary modes (i.e., road, rail, air, and water) in the mode choice model.
- Includes three types of trucks (light, medium, and heavy) in the vehicle choice and tour pattern model.
- Estimates freight tonnages annually and then converts truck tonnages to average daily tonnages. Simulates truck deliveries by the minute and aggregates to the CMAP regional time periods for assignment.
- Identifies truck deliveries as pick-up or drop-off. Includes no service-related truck tours or intermediate stops for driver meals, gas refills, or breaks.

Assumptions Made Regarding Agent/Behavioral Relationships

The model makes various assumptions regarding inputs to the model and relationships between buyer and seller agents. For example, in the PMG kernel, some input parameters reflect different assumptions regarding buyer tradeoffs between supplier cost and responsiveness and risk hedging. In addition, different sets of parameters and payoff weights are specified in the model to reflect assumed information available to agents and whether market prices are static or adjusted throughout game play. In general, PMG behavioral parameters reflect assumptions about the possible mindsets of buying and selling agents as they seek out and try to secure favorable procurement contracts for their establishments. The CMAP model recommends a baseline set of PMG parameters, motivated by the aspiration to represent plausible agent behavior under the following assumptions:

- Agents do not have perfect information about all agents in the market, but do have information about the agents with whom they have had trading encounters and know both their own rating of past trades and how their trading partners rated them.
- Agents learn through successive iterations, accumulating experiences, and updating their knowledge about agents with whom they have new trading encounters.
- Both buyers and sellers evaluate the potential for future trades with each other using weighted payoff values that consider the perceived strength of trading relationships, as opposed to pure cost minimization or revenue maximization.
- The commodity market under study is in a steady state, and agents are price-takers who do not affect average commodity prices in the short term.

- It is unknown whether buyers are of the type who tend to satisfice quickly and stick with their initial trading partners, or are of the type who are inclined to seek out potentially new and better trading partners.

Also, for import/exports of commodities, it is assumed that the amount produced by each country for a commodity represents a fixed production capacity (supply), and ignores the demand-supply impacts of sales to non-U.S. countries. Similarly, the model assumes that the amount that the United States exports to each country represents a fixed demand for U.S. goods and ignores the demand-supply effects of purchases from non-U.S. countries.

Modeled Performance Measures

Primarily, CMAP's current model looks at the tonnage and value of commodities shipped by mode. This has focused on commodities coming into and out of the region, but the model also looks at the flows of commodities between wide-ranging regions of the country to determine if the larger U.S. economy is being adequately represented. The current consultant contract will most likely yield a standard set of metrics that CMAP will use to compare scenarios. CMAP includes the following performance measures:

- Models annual tonnage shipped by mode to, from, and through the Chicago region.
- Models cost per ton of freight shipped, by mode.
- Models market share of international or regional trade.
- Models origin-destination (O-D) travel times, by mode and commodity.
- Models daily trucks, by time period and road segment.

Approach to Forecasting

The CMAP freight model is run as a standalone scenario (currently only a base year exists) through RStudio software. The truck-touring component of the freight model outputs a set of time-of-day truck trips in CMAP's modeling zone system that can serve as inputs to the regional trip-based model in place of the current truck demand used within the model. CMAP has verified that this functionality works but has not yet used freight model truck trip tables for any planning analysis. CMAP has not developed any actual scenarios for the PMG version of the freight model. A consultant contract is underway that will develop and test at least one alternative scenario for sensitivity testing purposes. This work will include the development of methods and procedures to modify input data as appropriate.

Types of Applications and Procedures

The current freight model is still in the development phase and has not been used for any planning analysis. The current consultant contract will calibrate the mode choice component of the freight model and will validate the model's output commodity flows. CMAP staff will begin to use the model for planning analyses after this work is completed (anticipated by the end of 2017). To date, CMAP has applied this system to a limited set of sensitivity tests (constrained to varying the PMG input parameters for a set of selected commodity markets).

Data

Geographic Scope

The CMAP freight model has multiple levels of resolution and can forecast freight flows between Chicago and the rest of the world (mesoscale). It also includes an intraregional truck-touring model (microscale). The different systems (meso and micro) 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:

- **National and International Zones**. Comprises domestic FAF4 zones and international FAF4 zones in broadest zone system. It is used for the FAF4 commodity flow input data. International zones include eight international regions used for imports and exports.
- **Statewide Traffic Analysis Zones (TAZs)**. Comprises traffic analysis zones that are smaller in size (within Chicago Urban Area and surrounding area of Illinois, Indiana, and Wisconsin) with subcounty-size TAZs (Figure 14) in midlevel zone system. This zone system is used during the establishment allocation and modes and transfers steps.
- **Regional TAZs**. Comprises TAZs that are smaller than statewide zones, but larger than passenger model zones (Figure 15) in the regional zone system. This zone system is used for all the truck-touring model components.

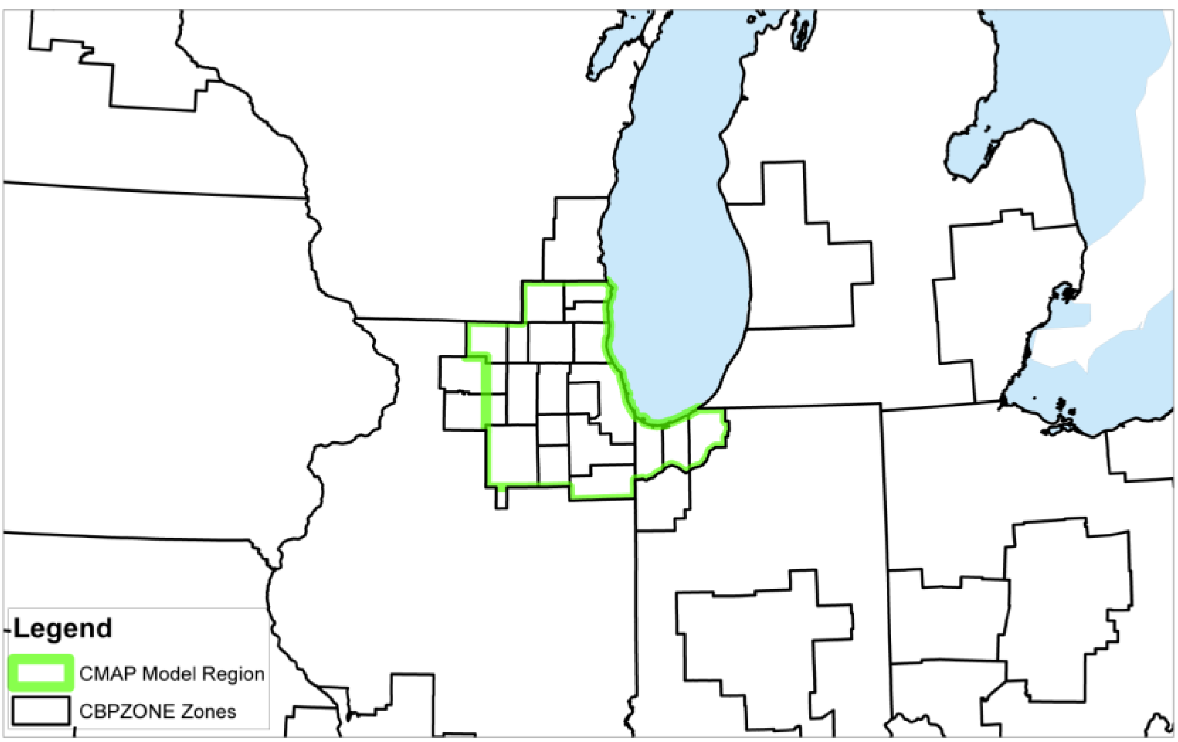

Figure 14. CMAP Statewide TAZs.
Source: (Cambridge Systematics, 2011)

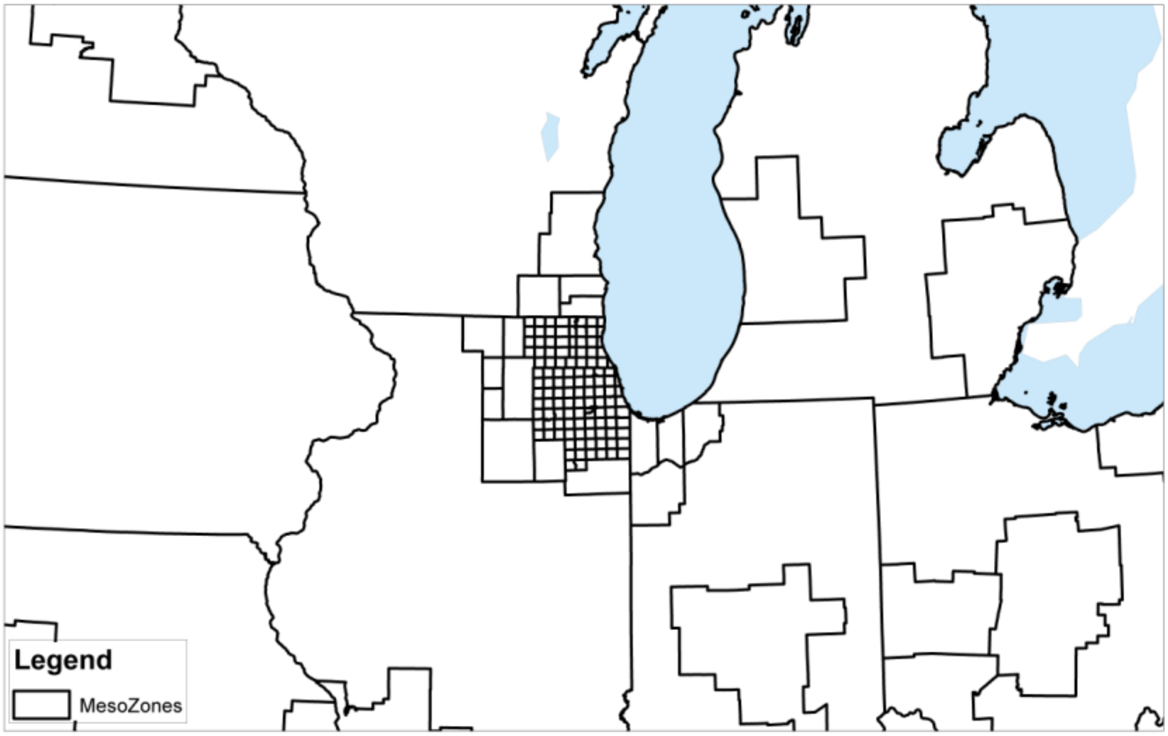

Figure 15. CMAP Regional TAZs.
Source: (Cambridge Systematics, 2011)

Data Inputs

The CMAP freight model uses the following data sources as data inputs:

- **Zone Systems**. Freight Analysis Framework (FAF) zone system (FHWA), county-level zone system (U.S. Census Bureau), and CMAP mesoscale zones.
- **Economic Data**. Input-Output (IO) Make and Use tables (BEA) and industry to commodity correspondences (BEA and Freight Activity Microsimulation Estimator [FAME]).
- **Employment Data**. County Business Patterns (CBP) data (U.S. Census Bureau) and CMAP employment data.
- **USA Census Trade Online**. Volumes of imports and exports of commodities flowing to and from the United States and other countries.
- **Networks.** Uses CMAP's mesoscale model freight network to derive skims. The model uses detailed networks of road and rail in the United States, but estimates detailed networks of air and water using simple functions of distance and the value of goods being transported.

Data Used for Estimating Model Parameters

The CMAP freight model uses the following main data sources for estimating model parameters:

- **Data collected for a national survey as part of the FAME project** (Samimi A. M., 2010). Uses these data to identify four distribution channels comprising combinations of intermodal terminals, warehouses, consolidation centers, and distribution centers (i.e., direct shipments, one type of intermediate stop, two types of intermediate stops, or three or more types of intermediate stops).
- **Commercial vehicle surveys collected in Texas**. Uses these data to predict shipment weight and number of shipments per year.
- **Research conducted by de Jong and Ben-Akiva** (de Jong, 2007). Adapts this research to use in the mode and intermediate transfer model to predict the mode and path of long-haul movements of freight based on a comprehensive accounting of transport and logistics costs.

Data Used for Model Calibration

Under the new model update contract, CMAP expects to calibrate the mode choice model used to estimate shippers' choices. This is anticipated to be accomplished by comparing the freight model-derived modal shares used to transport significant commodities or commodity groups within the national economy to modal shares reported by other data sources. These data sources may include (but are not limited to) the FAF data, the Public Use Waybill Sample, Waterborne Commerce Statistics Center data, and the 2012 Commodity Flow Survey (CFS) Public Use Microdata (PUM) file.

Data Used for Model Validation

CMAP plans to validate the PMG portion of the model against observed commodity flows (e.g., FAF data) as part of the new model update work. Two types of validation will involve comparisons with observed data where data are available, and in cases where data are not available, a process validation compares the outcomes of the model with anticipated outcomes based on the mathematical algorithm that the model is intended to simulate. The validation will examine several outputs from the firm synthesis and procurement market models that collectively lead to the shipment flow outputs produced by the model (e.g., location and magnitude of commodity production and consumption, spatial commodity flow patterns, and magnitude of commodity flows). The validation process design will depend on identifying what data are available to support validation. The geographic scale achievable using the FAF data is likely limited to FAF zone to FAF zone, which is essentially State or major metro area to State or major metro area. The validation task will likely rely on a similar set of datasets to those used to calibrate the mode choice model.

Data Desired, but not Found

Some of the desired—but unobtainable—data for use in the model included the following:

- Data for estimating logistics costs calculations (e.g., storage costs, warehouse handling charge).
- Data for maximum load weight of truck types in the vehicle tour choice pattern component of the model.

Detailed information about the model and the freight datasets is not yet available online.

FLORIDA STATEWIDE

Methodology

The Florida Department of Transportation's Freight Supply Chain Intermodal Model (FreightSIM) (RSG, 2015) is a travel demand model component integrated into the Florida Statewide Model (FLSWM). FreightSIM simulates the transport of freight between supplier and buyer businesses in the United States, focusing on Florida-specific movements. FreightSIM produces a list of commodity shipments by mode and converts those to daily truck trip tables that can be assigned to the national and statewide networks in the FLSWM along with trip tables from the passenger model. The approach used in the development of FreightSIM employs supply chain and economic methods to explicitly model aspects of freight decision-making behavior. The model is intended to provide decision-makers with better information to make decisions about transportation investments and policies. The supply chain methods at a national scale in this framework have been adapted to include additional level of detail (zone system) in Florida.

Supply Chain Modeling Needs

Providing freight mobility in a cost-effective manner requires an understanding of supply chain and logistics behavior and an evaluation of investments in transportation infrastructure and services. It also requires anticipating the effects of any government and private sector decisions that affect the transportation system and its uses. The development of a multimodal supply chain shipment model was focused on addressing this overall objective. Trends affecting freight mobility in Florida over the next 50 years include an innovation economy with emerging megaregions and industries such as aerospace, clean energy, life sciences and creative industries; shifting global markets and development patterns; new communication technologies and environmental stewardship challenges; and the changing role of the public and private sectors (Florida Department of Transportation, 2010). 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.

A multimodal supply chain shipment model of goods movement for Florida was developed to assist with the following:

- Inform infrastructure investment decisions.
- Evaluate congestion on Florida's highways.
- Test the effectiveness of statewide transportation policies on mobility and the economy.
- Produce multimodal system performance measures for freight.
- Evaluate the effects of private sector decisions on the State transportation system.
- Provide regional agencies with intercity freight travel for regional planning purposes.

The goal for FreightSIM is to account for changes to freight mobility based on these types of policies.

Model Structure, Component Interactions, and Segmentation

FreightSIM simulates the transport of freight between each supplier and buyer business in the United States. Figure 16 illustrates these processes and identifies major input and output data. This modeling system includes the selection of business locations and trading relationships between businesses; it also includes the resulting commodity flows, distribution channel, shipment size, and mode and path choices for each shipment made annually:

- **Firm Synthesis**. Synthesizes all establishments in the United States and a sample of international establishments.
- **Supplier Firm Selection**. Selects supplier establishments for each buyer establishment, by type.
- **Goods Demand**. Predicts the annual demand (in tonnage) for shipments of each commodity type between each establishment in the United States.
- **Firm Allocation**. Allocates firms in each county to TAZs 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). The model encompasses all of Florida and 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. The validation data are for rail, air, and waterway flows and these data are retained as trip tables instead of being assigned.

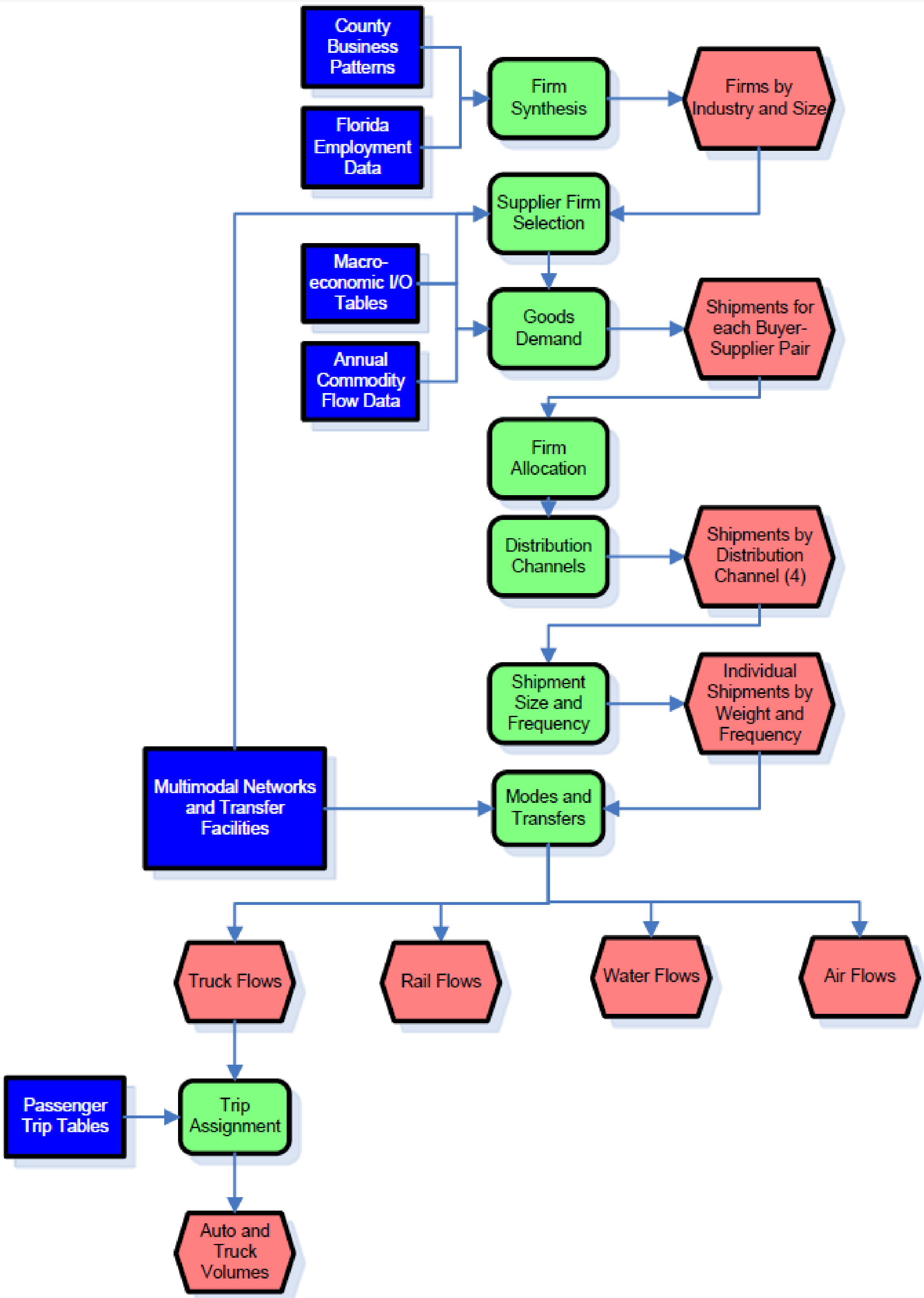

Figure 16. FreightSIM National Supply Chain Model Structure.
Source: (RSG, 2015)

Market Segmentation (Industry, Commodity, Mode, Vehicle Type, Temporal, Activity Type)

FreightSIM employs several different types of market segmentation depending on the unit of analysis of each model component. The firm synthesis model characterizes business establishments by location (TAZ), establishment size (eight employment categories ranging from 1–19 employees to over 5,000 employees), and industry (six-digit Census Bureau NAICS categories). The firm synthesis model is controlled at the TAZ level within Florida using the statewide employment forecast data. The employment forecasts are grouped into three employment categories that are aggregations of NAICS categories. The commodity production and consumption by business establishment uses the BEA's six-digit NAICS categories, which is slightly aggregated in comparison to the U.S. Census Bureau's NAICS categories used for the industrial classification of the business establishments.

The supply chain model works with FAF commodity flow data and uses the 43 SCTG categories for segmentation of shipment commodity. The distribution channel of the shipment flow through the supply chain is segmented into direct shipments using one, two, or three transfers at distribution centers or intermodal transshipment locations. The supply chain model allocates shipments into size categories using a two-stage process, ultimately calibrating the distribution to the nine shipment-size categories, ranging from less than 50 pounds to more the 100,000 pounds used by the CFS. The shipments are allocated to one of four main modes (i.e., truck, rail, water, or air), with the intermodal paths being some combination of those modes (e.g., truck-rail-truck). The conversion to trip tables of the outputs from the supply chain model uses truck percentages for light, medium, and heavy trucks (FHWA classes 2–3, 4–7, and 8–13, respectively). The trip tables are divided into four time-specific trip tables (AM peak, midday off-peak, PM peak, and nighttime off-peak) using fixed factors.

Modeled Performance Measures

FreightSIM includes the following performance measures:

- Models shipment size and weights, by commodity.
- Models truck, rail, air, and water trips, by district.
- Models annual import and export flows, by port.
- Models daily truck volumes, by district, area type, facility type, and screenline.
- Models daily truck travel times for select O-D pairs.

Approach to Forecasting

The freight demand, supply chain, and mode and transfer components of FreightSIM are run for each forecast year using the R open-source statistical programming platform and are integrated with the FLSWM that is implemented in the Cube software. The statewide model includes the following primary groups or steps:

- Building highway network.
- Statewide passenger model.

- Statewide freight supply chain intermodal model (FreightSIM).
- Statewide passenger and freight joint highway assignment.

FreightSIM's trip table outputs are combined with those from the other components of the model—nonfreight trucks and passenger trips—and assigned to the highway network in the final model step.

FreightSIM requires travel time and costs from future-year highway networks and nonhighway freight networks, future-year commodity flow forecasts (e.g., FAF data forecasts or alternative commodity flow forecasts developed by the model user), future-year employment controls at the TAZ level, and future-year distribution center locations to create a future scenario. Any additional future-year inputs required to develop future-year passenger vehicle forecasts are also required to run a full statewide model scenario for all travel, such as household and population forecasts.

Types of Applications and Procedures

The FreightSIM multimodal statewide supply chain shipment model could support multiple types of policy analyses:

- **Modal alternatives**. Direct competition exists between air, rail, water, and truck for freight movements, and any infrastructure investments being considered should be evaluated in the context of this competition. These alternatives are evaluated nationally and—to a lesser degree—internationally to capture any impacts in Florida.
- **Pricing**. Many aspects of pricing can and should affect statewide freight forecasts. Pricing can be a strategy to manage demand or raise revenues (e.g., toll roads, gas taxes, mileage fees). Pricing affects the travel decisions of drivers, shippers, carriers, and 3PL establishments differently.
- **Economics**. Policies to improve economic conditions will affect freight and goods movement. Economic conditions are currently inputs to FreightSIM and could be tested by adjusting these inputs to understand the effects on freight mobility of a greater demand for goods. Higher employment in the State will lead to additional production and consumption of commodities, which can be represented by alternative employment and commodity flow inputs.
- **Environmental**. Policies to reduce transportation-related emissions can have effects on freight and goods movement. An increase in the gas tax will influence gas consumption and potentially reduce vehicle miles traveled (VMT). Carbon taxes may also affect the cost of freight transport. The Environmental Protection Agency may change fuel standards for trucks, which will affect the transport cost for trucks.
- **Safety**. Policies such as driver hours-of-service regulations and technologies to reduce accidents for hazardous materials transport will affect decisions on the cost to transport goods and on what modes to use for certain goods.

- **Regional**. Regional policies such as taxes, tolls, or local delivery times will result in different freight mobility in different cities. Truck route restrictions and truck size and weight limits can also affect route decisions.
- **Airport, Seaport, or Rail Planning**. Policies made by airports, seaports, or rail operators regarding new capacity, intermodal terminals, or environmental effects can be evaluated using FreightSIM.

FreightSIM is designed to be a policy sensitive freight model with the following applications:

- Inform infrastructure investment decisions.
- Evaluate congestion on Florida's highways.
- Test the effectiveness of statewide transportation policies on mobility and the economy.
- Produce multimodal system performance measures for freight.
- Evaluate the effects of private sector decisions on the State transportation system.
- Provide regional agencies with intercity freight travel information for regional planning purposes.

Data

Geographic Scope

FreightSIM uses three levels of spatial resolution:

- **National and International Zones**. Comprises domestic and international zones from the FAF3 and is the broadest zone system. These zones are used to represent all States except Florida, Georgia, and Alabama. Eight international zones account for imports and exports. The firm synthesis model uses this zone system.
- **Statewide County-Level Zones**. Comprises counties in Florida, Georgia, Alabama, and FAF3 zones outside of these three States (Figure 17) and is an intermediate zone system. This zone system is used in several model processes, including firm synthesis and supplier selection.
- **Statewide TAZs**. Comprises TAZs that are smaller in size within Florida and the parts of Georgia and Alabama (Figure 18), combined with the county or FAF3 zones in the rest of the United States. This zone system is used during business location assignment, mode choice, and assignment.

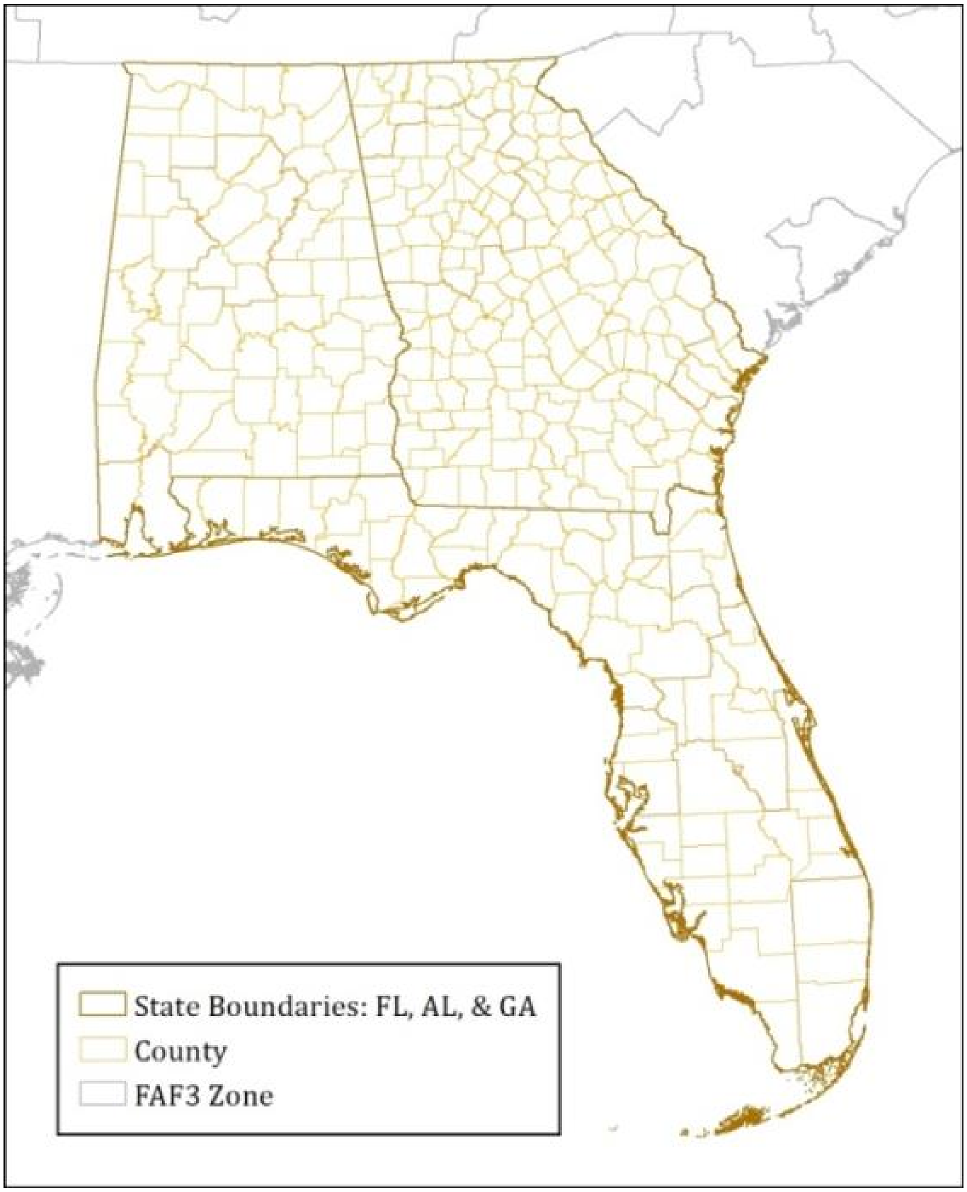

Figure 17. FAF Zones and Counties In Florida, Georgia, and Alabama.
Source: (RSG, 2015)

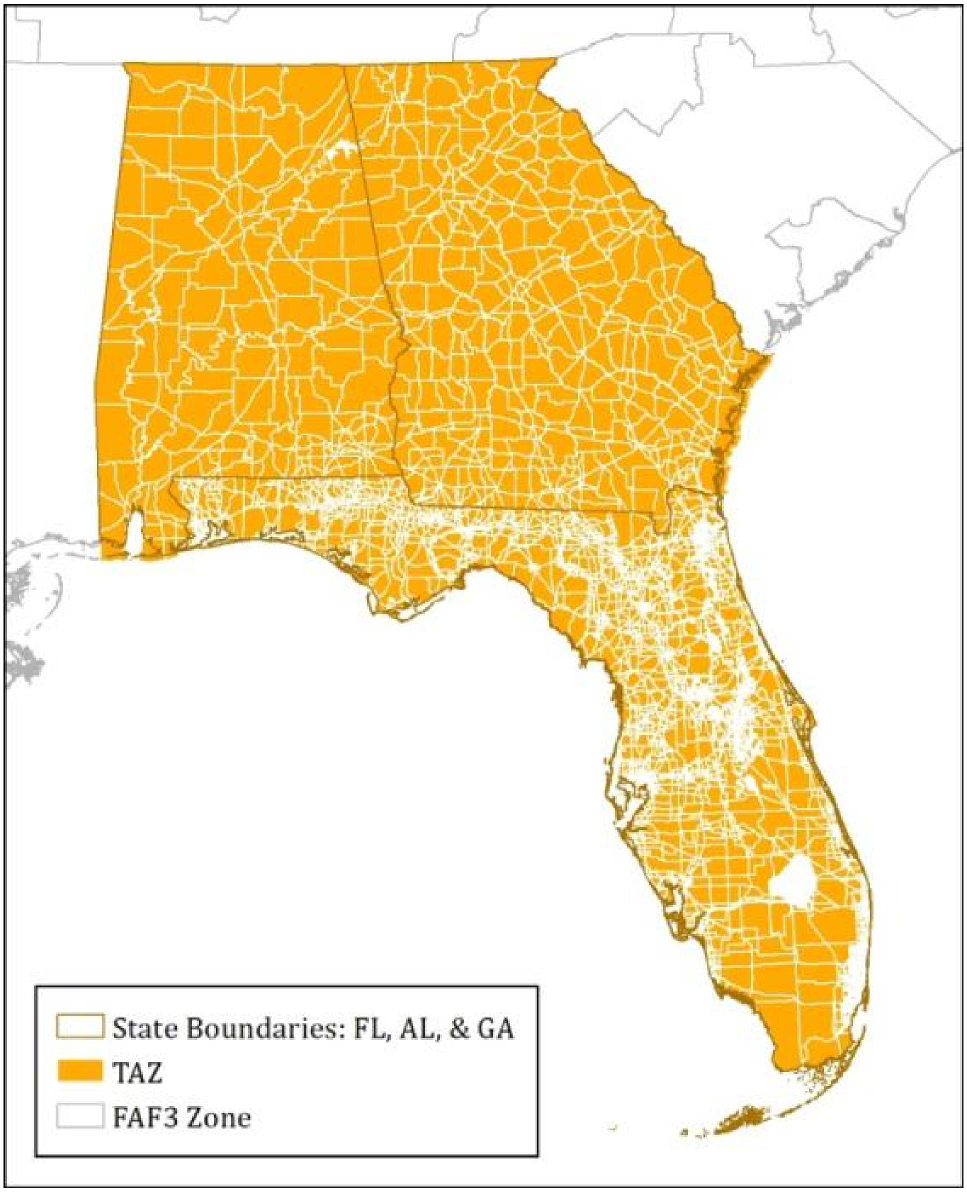

Figure 18. Statewide Traffic Zone System (Florida, Georgia, and Alabama).
Source: (RSG, 2015)

Data Inputs

Several data inputs were used for FreightSIM's development, both as main inputs or as additional, miscellaneous datasets. Table 4 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 an overview of the data.

Table 4. Data Sources for FreightSIM.

Type of Input	Input	Source	Description

Type of Input	Input	Source	Description
Zone Systems	FAF3 Zone System	FHWA	Large regions, such as Combined Statistical Areas, or states
Zone Systems	County-Level Zone System	U.S. Census Bureau	Counties within FL/GA/AL
Zone Systems	TAZ-Level System	Florida Department of Transportation (FDOT)	TAZs within FL, counties (within the GA/AL) and FAF3 zones (outside of FL/GA/AL)
Network Elements	Network links	FDOT, Oak Ridge National Laboratory (ORNL) and U.S. Army Corps of Engineers	Highway (FDOT), rail (ORNL), and waterway network (U.S. Army Corps of Engineers) links
Network Elements	Transport and logistics nodes (TLN)	FDOT, ORNL, Bureau of Transportation Statistics (BTS)	Specific nodes within Florida; representative nodes outside of Florida
Network Elements	GCD	ORNL	Distance between all county-level O-D pairs in the United States
Network Elements	GCD to foreign zones	Created by project team	Distance between U.S. counties and foreign FAF3 zones
Economic Data	IO Make and Use Tables	U.S. BEA	Values of commodities exchanged between industries
Economic Data	Industry to Commodity Correspondence	FAME	List of SCTG commodities produced, by each NAICS6 industry
Economic Data	NAICS6 Industry to IO Industry Correspondence	U.S. BEA (2002)	Correspondences between detailed NAICS6 industries and aggregated NAICS IO industries
Freight Flows	FAF3 Commodity Flows	FHWA	Commodity flows between FAF3 zones

Type of Input	Input	Source	Description
Freight Flows	Commodity Flow Survey	FHWA	Shipment sizes, by commodity and tonnages
Employment Data	CBP Data	U.S. Census (2010)	Employment, by industry
Employment Data	InfoGroup data	FDOT	Business operating in Florida
Validation Data	Truck Counts	FDOT	Medium and heavy truck counts
Validation Data	Truck Trip Origins and Destinations	American Transportation Research Institute	Sample of truck trips by county and TAZ O-D
Validation Data	Weigh-in-Motion (WIM) Data	FDOT	Truck weight distribution
Validation Data	Carload Waybill Data	U.S. Department of Transportation (USDOT) via FDOT	Complete restricted dataset of Carload Waybills
Validation Data	T-100 Data	BTS	Air freight segment and market data
Validation Data	Port Import/Export Reporting Service (PIERS) Data	FDOT	Import/export shipment data by port

Source: (RSG, 2015)

Data Used for Estimating Model Parameters

FreightSIM uses the following main data sources for estimating model parameters:

- **Supplier-Selection Model Parameters**. Transferred from earlier freight modeling work for CMAP (Cambridge Systematics, 2011) and (Samimi A. M., 2010). Coefficients used as the probability of a supplier being paired with a buyer establishment (type). These coefficients were asserted and not estimated due to the unavailability of these data.
- **Distribution Channel**. Transferred from earlier modeling work for CMAP (RSG, University of Illinois at Chicago and John Bowman, 2012). The distribution channel

model was estimated using data collected for a national survey as part of the **FAME project** (Samimi A. M., 2010).

- **Shipment Size**. Transferred from earlier modeling work for CMAP (RSG, University of Illinois at Chicago and John Bowman, 2012). The **commercial vehicle surveys collected in Texas** were used to estimate the model of shipment sizes.
- **Mode and Transfer Choice**. Mode and transfer choice model parameters were transferred from earlier freight modeling work for CMAP (Cambridge Systematics, 2011). This model was based on the formulation developed by de Jong and Ben-Akiva (de Jong, 2007). The formulation reflects the real-world decision-making of freight movers by accounting for different components of costs. Estimation of the parameters in the formulation was not possible without new data collection, but additional research on a few parameters led to revised assumptions for the Florida application:
  - Fixed cost per order (obtained from (Dominic, 2009) and (Benchmarks, 2006))
  - Storage costs per unit per year (based on the assumption provided in (Colonial Diversified, 2009))
  - Transportation and intermediate handling cost (adapted from (Leachman, 2005)).
  - Level-of-service parameters (adapted from (Leachman, 2005), (Bureau of Transportation Statistics, 2008) and (CSX, 2013)).
  - Path cost parameters (initial application in Chicago was a demonstration and these parameters were asserted (Cambridge Systematics, 2011) rather than estimated. Further research and consideration resulted in recommended values for several parameters).
  - Safety stock constants and categorization of commodities (based on the idea and assumptions in (Fisher, 1997)).
  - Lead time, standard deviation in demand and lead time and mode capacities (based on the research and assumptions in (Notteboom, 2011) and (CSX, 2013)). Lead time, standard deviation in demand, and lead time and mode capacities (based on the research and assumptions in (Notteboom, 2011) and (CSX, 2013)).
- **Truck Payload and empty factors**. Based on Vehicle Inventory and Use Survey (VIUS) data (VIUS, 2002).

Data Used for Model Calibration

FreightSIM uses the following main data sources for model calibration:

- Summaries of American Transportation Research Institute (ATRI) truck Global Positioning System (GPS) data (to support calibration of the distribution of truck trips).
- WIM data provided by FDOT (used during model calibration to inform adjustments to vehicle loading factors used to convert shipment tonnages to truck trips).
- The PIERS data provided by FDOT (used to develop calibration weights for the mode and transfers model, and the model of import and export volumes, by port).

- An online establishment survey done by University of Illinois at Chicago (Samimi A. M., 2010) results on proportions of shipments by distribution channel (used as calibration targets and for adjusting the alternative specific constants in the distribution channel model). The number of shipments by distribution channel type, commodity, and location were developed using the survey study results and were used to adjust the constants in the distribution channel model.
- CFS data on the distribution of shipment sizes by commodity (used as calibration targets and for adjusting the alternative specific constants in the shipment-size model).

Data Used for Model Validation

FreightSIM uses the following main data sources for model validation:

- TRANSEARCH commodity flows (used to validate mode and transfer choice model).
- Truck counts provided by FDOT (used to validate truck trip assignment model).

Table 5 shows the details of validation tests.

Table 5. FreightSIM Model Validation Tests.

Model Component	Validation Test	Data Source	Process
Shipments and their Size	Shipment size by establishment pair, commodity type	CFS TRANSEARCH data	Compare the shipment sizes and weights distribution by commodity
Mode-Transfer	Modal volume	TRANSEARCH data (incorporating Carload waybill data)	Compare mode shares by commodity group and movement/location
Truck Trip Assignment	Truck volumes	Highway truck counts, by vehicle type	Compare daily truck volumes by district, county, facility and screenline

Source: (RSG, 2015)

Data Desired, but not Found

Some of the desired—but unobtainable—data for use in the model included the following:

- Data for estimating logistics costs calculations (e.g., storage costs, warehouse handling charge).
- Data for maximum load weight of truck types in the mode and transfer choice component of the model.

Detailed information about the model and the freight datasets is available online at:

- FreightSIM Wiki (enumerated web address: https://rsginc.atlassian.net/wiki/spaces/FREIGTSIM/overview).

WISCONSIN

Methodology

Supply Chain Modeling Needs

The Wisconsin Department of Transportation's (WisDOT's) main needs from its freight model are forecasts of truck volume on the roadways. WisDOT maintains data on the commodities being moved, and the origins and destinations of freight moving to, from, and through Wisconsin. WisDOT uses its freight model to answer the following questions:

- How many trucks are moved?
- Where are the trucks coming from and going to—locations within Wisconsin or outside of the State?
- What are the trucks carrying?
- How does truck volume or routing change based on the socioeconomic characteristics of an area or the freight facilities available?

WisDOT requires forecasts of trips by all modes that carry freight—not just trucks—to prepare these truck forecasts, evaluate changes in modal share, and provide forecasts of freight travel by other modes. Further, Wisconsin needs accurate tools and data for evaluating freight corridors entering Wisconsin, and for freight facilities in counties/metropolitan areas adjacent to Wisconsin.

WisDOT currently operates a vehicle trip-based model (where trips by different modes are not linked into supply chains). WisDOT has tested a supply chain model where the cargo carried by those trips are linked. According to WisDOT, the supply chain model as it was currently formulated, did not do a good job of evaluating changes in truck volume given changes in the socioeconomic characteristics of a given area, which was related to limitations inherent in the input data available. The inherent limitations of the input data are primarily related to the coarse granularity of the O-D freight flow data available to WisDOT (the FAF data). In one analysis scenario conducted as part of the model development, the model predicted fewer trucks going to and from Kenosha County—with the presence of a newly constructed Amazon fulfillment center there—than without it.

As tested by WisDOT, the supply chain model accurately predicts changes in mode shift due to changes in the use of supply chains or system intermodality. In a different analysis scenario conducted as part of model development, the model showed that given the presence of an intermodal rail terminal in Milwaukee County, there would be an increase in mode share by rail containers in Wisconsin and nearby Minneapolis, Minnesota, and Rochelle and Chicago, Illinois. However, only a small portion of this freight tonnage was taken away from trucks, which are by far the dominant mode of freight transport in Wisconsin. (The supply chain model showed more rail tonnage taken away from the Minneapolis-area intermodal terminals than from the closer and more active Chicago terminals—this is counterintuitive to the expectations from adding a Milwaukee intermodal terminal.)

According to the agency, the short- and long-term applications of the WisDOT supply chain freight model are unclear at the time of writing this synthesis. The primary need of WisDOT from its freight model is to conduct evaluations like what was described in preceding paragraphs; WisDOT thinks that the supply chain model does not accurately evaluate truck volumes. There may be commodities or commodity groups where one model is preferable to another, particularly for mode allocation. For bulk commodities, the supply chain model seemed to slightly overestimate truck allocations, while also underestimating rail volumes. For finished goods, the supply chain model seemed to reverse this bias, with the rail mode seeing higher estimates than identified under the FAF. This appears to be a legacy of the origins of the modified Wisconsin supply chain model in the Chicago-area metropolitan planning organization's model; the presence of many intermodal facilities in the Chicago region allows greater opportunity for rail shipments of finished goods than in Wisconsin. Further, some freight movements are more conducive to a chain model, while others are better represented through O-D modeling. Examples of supply chain trips for Wisconsin's freight include the collection of milk by tanker trucks, the distribution of fuel oil or propane, and the wholesale or corporate distribution of consumer products at multiple retail locations.

Meanwhile, the O-D model best captures the movement of wood to paper mills, sand, and other aggregate to processing facilities, and coal to utility plants. Should the FAF be refined down to smaller regions, then that data could be used to test and compare the supply chain model with Wisconsin's existing trip-based model. Such a test could apply each model to a selection of typical bulk, semifinished, and finished goods, evaluating the accuracy of that model against specific freight categories or commodities. The refined data would also better identify corridors and modes used for cross-border and multistate freight movements.

Model Structure, Component Interactions, and Segmentation

The Supply Chain Model includes the following component models:

- Firm synthesis.
- Supplier selection.
- FAF3 flow apportionment.
- Business location assignment.
- Distribution channel.
- Shipment size.
- Mode-path selection.

Figure 19 shows the Wisconsin freight model structure.

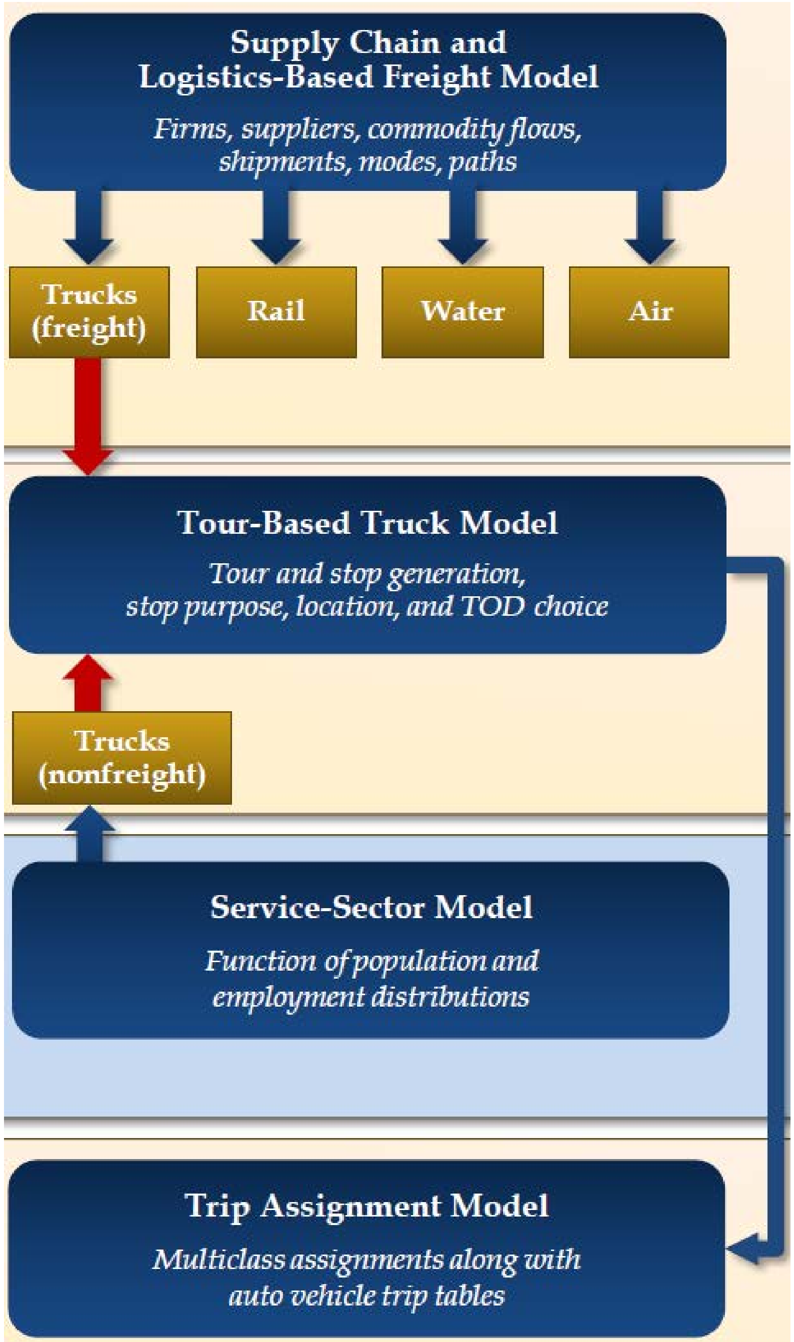

Figure 19. Wisconsin Freight Model Structure.
Source: (Cambridge Systematics, 2016)

The service sector model is not part of the supply chain model developed for WisDOT and it is included here for illustrative purposes only. A supply chain tour-based truck model was developed for WisDOT, but it did not yield meaningful information regarding local truck tours due to the coarse granularity of the underlying FAF3 input data. The lack of meaningful information was also attributable to the forecast usage of truck tours exclusively within supply chains (only truck tours occurring as part of supply chains were tested).

Market Segmentation (Industry, Commodity, Mode, Vehicle Type, Temporal, Activity Type)

Table 6 shows commodities and respective industries in the model. The model includes five modes (Source: (Cambridge Systematics, 2016) (Cambridge Systematics, 2016) Table 7).

Table 6. Wisconsin Model's Commodities and Industries.

Commodity	Industry
Live animals and fish	Farm products
Cereal grains (including seed)	Farm products
Other agricultural products, except for animal feed	Farm products
Animal feed and products of animal origin, n.e.c.	Food
Meat, fish, seafood, and their preparations	Food
Milled grain products and preparations, bakery products	Food
Other prepared foodstuffs and fats and oils	Food
Alcoholic beverages	Food
Tobacco products	Misc. nondurable manufacturing
Monumental or building stone	Nonmetallic minerals
Natural sands	Nonmetallic minerals
Gravel and crushed stone	Nonmetallic minerals
Nonmetallic minerals, not elsewhere classified	Nonmetallic minerals
Metallic ores and concentrates	Metallic ores
Coal	Coal and crude petroleum
Crude petroleum	Coal and crude petroleum
Gasoline and aviation turbine fuel	Petroleum products
Fuel oils	Petroleum products

Commodity	**Industry**
Coal and petroleum products, not elsewhere classified	Petroleum products
Basic chemicals	Chemicals
Pharmaceutical products	Chemicals
Fertilizers	Chemicals
Chemical products and preparations, not elsewhere classified	Chemicals
Plastics and rubber	Rubber/plastics
Logs and other wood in the rough	Lumber
Wood products	Lumber
Pulp, newsprint, paper, and paperboard	Paper
Paper or paperboard articles	Paper
Printed products	Misc. nondurable manufacturing
Textiles, leather, and articles of textiles or leather	Misc. nondurable manufacturing
Nonmetallic mineral products	Clay, concrete, glass
Base metal in primary or semifinished forms and in finished basic shapes	Metal
Articles of base metal	Fabricated metal products
Machinery	Machinery
Electronic and other electrical equipment and components and office equipment	Misc. durable manufacturing
Motorized and other vehicles (including parts)	Transportation equipment
Transportation equipment, not elsewhere classified	Transportation equipment
Precision instruments and apparatus	Misc. durable

Commodity	Industry
	manufacturing
Furniture, mattresses and mattress supports, lamps, lighting fittings, etc.	Misc. nondurable manufacturing
Miscellaneous manufactured products	Misc. durable manufacturing
Waste and scrap	Waste
Mixed freight	Secondary traffic and drayage

Source: (Cambridge Systematics, 2016)

Table 7. Wisconsin Supply Chain Model's Mode and Vehicle Type.

Mode	Vehicle Type
Truck	Long-haul and local trucks
Rail	Vehicles not explicitly modeled or assigned—mode shares determined
Rail intermodal	Vehicles not explicitly modeled or assigned—mode shares determined
Water	Vehicles not explicitly modeled or assigned—mode shares determined
Air	Vehicles not explicitly modeled or assigned—mode shares determined

Source: (Cambridge Systematics, 2016)

The WisDOT's statewide supply chain freight model is an average daily model. Time-of-day assignment methods can be employed in tour-based truck models, but these were not employed in this test of the supply chain model for Wisconsin. The Wisconsin supply chain model forecasts multimodal cargo transport.

Modeled Performance Measures

The performance measures that are modeled in the WisDOT's statewide supply chain freight model are mostly the traditional performance measures:

- Tonnage, by mode (mode share).

- Truck volume.
- Truck volume-to-capacity.[2]
- Truck VMT.
- Truck VHT.

Approach to Forecasting

The WisDOT statewide supply chain freight model as tested, was controlled by the basic multimodal O-D patterns in the FAF data. The model did forecast changes in the allocations of those multimodal O-Ds among different supply chains, but it was unable to change the multimodal O-D table in response to changes to Wisconsin's economy. By contrast, WisDOT's trip-based statewide model does forecast the multimodal O-Ds of freight based on changes in Wisconsin's economy.

Types of Applications and Procedures

WisDOT's statewide supply chain freight model was run on an R-Code platform and interface. It was not integrated with WisDOT's trip-based passenger model. Scenario creation typically involves making changes to network characteristics (like a proposed roadway capacity expansion or speed limit change) or socioeconomic characteristics (like proposed land development). All other model parameters are typically maintained between base and alternative scenarios.

Data

Geographic Scope

The WisDOT's statewide supply chain freight model zone structure is national for the allocation among supply chains, with greater detail within and near Wisconsin. The model zone structure for supply chain freight zones are counties in Wisconsin and neighboring states, the remainder of FAF regions in neighboring states, and FAF zones in all other U.S. States.

Data Inputs

WisDOT acquired and utilized the following datasets to develop the statewide supply chain freight model:

- FAF commodity flow data.
- CBP data.
- TAZ shapefiles.
- Socioeconomic data (employment by type).
- IO Make and Use Tables (BEA).

[2] Truck volume divided by total capacity.

- Highway and rail network shapefiles.
- Shapefiles of intermodal facility, distribution center, and warehouse locations.

Data Used for Estimating Model Parameters

The WisDOT model uses the following main data sources for estimating model parameters:

- FAF3 data (for payload factors).
- ATRI truck GPS data (for the truck-touring model parameters).
- VIUS data (for payload factors).
- University of Illinois's FAME model (for firm synthesis and supply chain allocation model parameters).

Data Used for Model Calibration/Validation

WisDOT performed a reasonableness check by aggregating the supply chain groups (e.g., direct truck, direct rail, air, water). Flows were also aggregated by commodity groups that were also used to renormalize the tonnages after the original allocation to supply chains. The results were then compared to the FAF modal and commodity group aggregations for calibration/validation. Since the allocation to supply chains were done to total tons over all modes, comparing with similar aggregations from FAF data means that the allocation worked correctly. The following main data sources were used for model calibration and validation:

- TRANSEARCH data.
- External station truck counts.
- Comparison of external flows vs. existing freight model flows.
- Comparison of freight mode shares vs. existing freight model shares.
- Truck VMT, by county.
- Vehicle classification data at specified screenlines.

Data Desired, but not Found

A county-level (or TAZ-level) multimodal freight cargo O-D table was the main data desired, but such an independent data source was not available for validation against the supply chain freight model's forecasts.

Detailed information about the model and the freight datasets is not yet available online.

PHOENIX

Methodology

The Maricopa Association of Governments (MAG), Arizona Department of Transportation (ADOT), and Pima Association of Governments (PAG) submitted a joint proposal to the SHRP2 C20 IAP to develop an operational megaregional multimodal agent-based behavioral freight model. The proposal was successful and in September of 2014 the work began. SHRP2 C20 IAP grant and additional support from the agencies provided necessary funding and in-kind contributions that allowed to successfully complete the project. The development took twenty-four months. As a result, a regional behavior-based freight transportation model was developed for the Arizona Sun Corridor megaregion for evaluating freight policy effects at the regional scale. Relevancy, importance, and timeliness of the model for the planning tasks was underlined by the fact that Arizona and the MAG region in particular rebounded from the recession. Arizona Sun Corridor megaregion, which includes MAG region, continues to be one of the fastest-growing megaregions in the country.

Supply Chain Modeling Needs

MAG, ADOT and PAG staff identified a need for the future development of the regional freight forecasting models. Arizona's Sun Corridor megaregion covers portions of five counties that include the MAG and PAG regions and is home to 8 out of 10 Arizonans. The Sun Corridor is also a major gateway for fresh produce and manufactured goods from busy freight ports on the U.S.-Mexico border. Arizona's population growth rate is expected to be robust in the upcoming decades and be one of the highest in the country, driven largely by activity in the Sun Corridor. FAF shows high growth rates in goods movement in Arizona. Given the expected growth in freight and its importance to the regional economy, MAG improved its capabilities to analyze freight demand in continuation of its state-of-the-practice truck models and developed a behavior-based freight modeling. MAG took a lead on the project and sought a behavioral-based freight modeling solution to support its organizational goals. MAG's goals included development of the regional transportation plan, development of freight transportation plans, and fostering transportation-related regional economic development. Moreover, MAG's extensive experience in developing and applying regional truck models led to a realization of the importance of behavior-based facets of freight decision-making. ADOT, MAG, and PAG realized that the decisions of shippers and carriers significantly affect regional transportation forecasting. A truck tour-based model recently developed by MAG resulted in noticeable improvements in forecast validations. The MAG's freight modeling tool addresses the changing conditions in freight supply and demand in the MAG region. It also captures transportation decisions, such as mode choice and the use of logistical handling facilities (e.g., intermodal yards) for individual establishments and simulates individual vehicle movements, allowing MAG to analyze impacts of new infrastructure projects at a highly detailed level.

Model Structure, Component Interactions, and Segmentation

The proposed modeling framework, that largely remained intact throughout the development, is shown in Figure 20. This figure provides information on the data inputs necessary to apply the individual modeling components in the new model system, data necessary to estimate various components of the supply chain and tour-based models, the supply chain models, key outputs that are produced from each modeling component, different geographic zones, and data that will be used to calibrate each component and validate the new model system. The flow chart detailing implementation of the supply chain, transport, mode, and path choice models is shown in Figure 21.

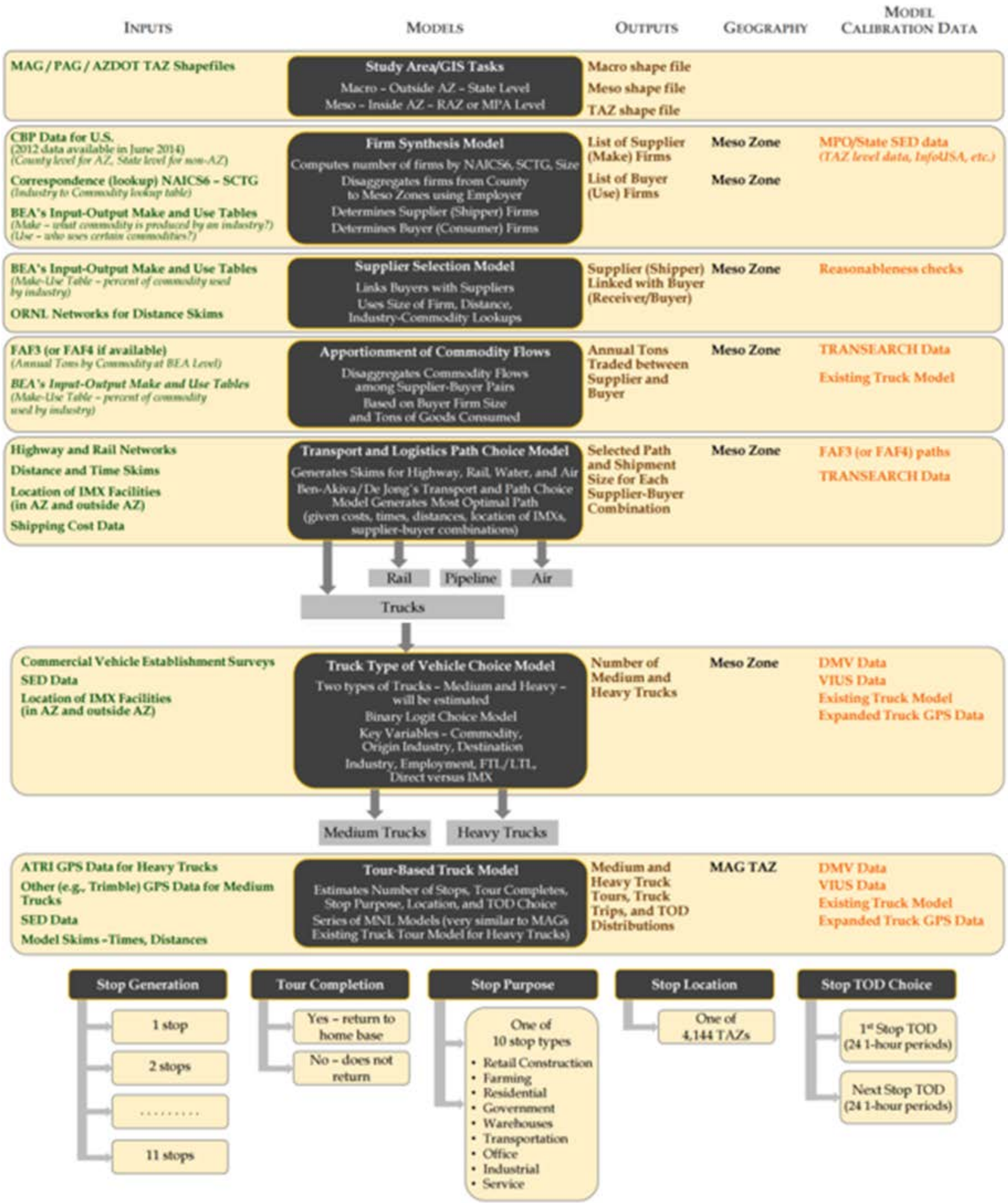

Figure 20. Individual Components Of The Proposed Behavior-Based Freight Model.
Source: (Maricopa Association of Governments, 2017)

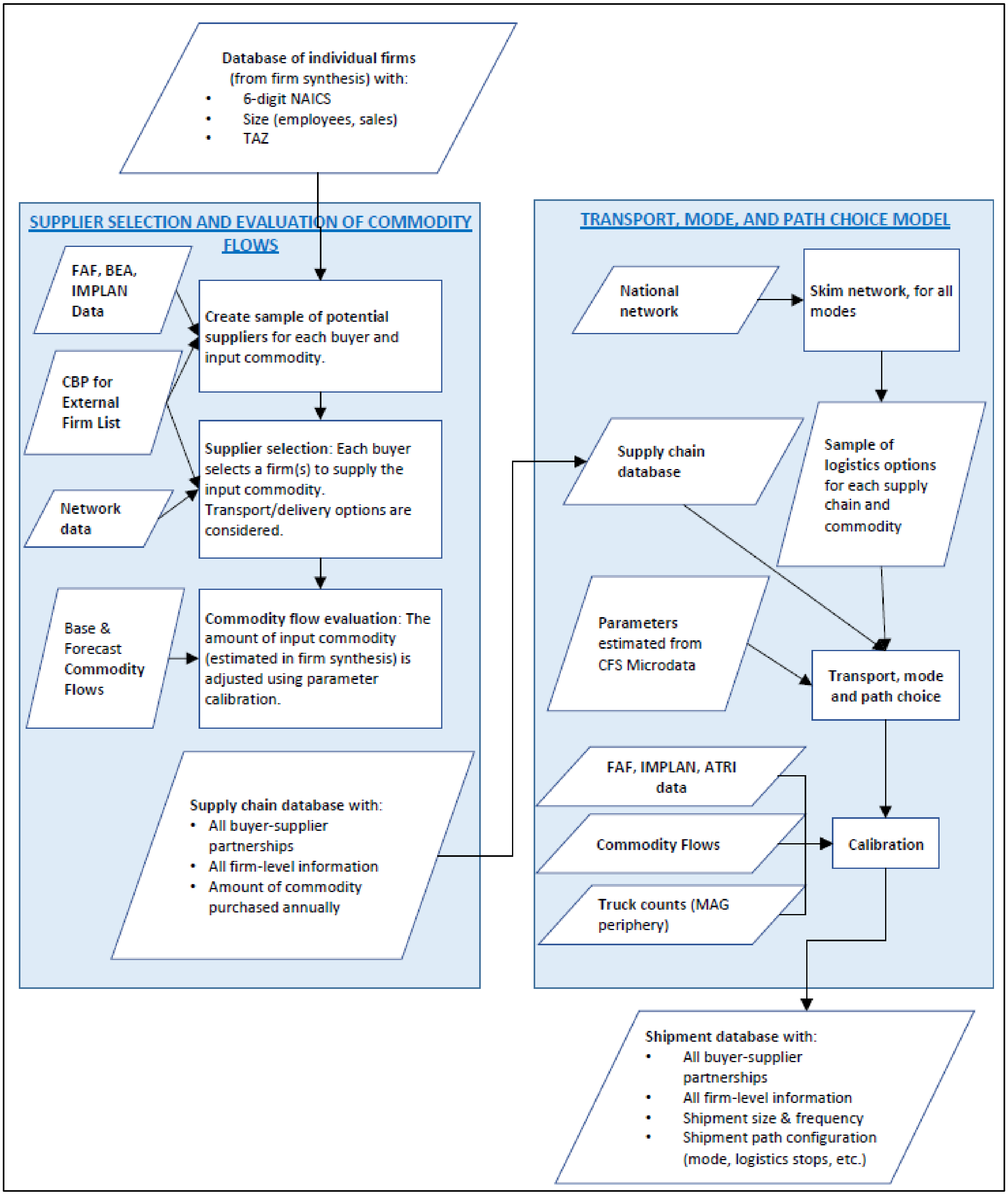

Figure 21. MAG Behavior-Based Supply Chain and Freight Transportation Framework.

Source: (Maricopa Association of Governments, 2017)

Overall freight modeling framework included the following three major components:

- **Firm Synthesis Model**. Synthesizes establishments and simulates regional establishments mainly by industry and by size in the base year and reflects firm evolution, including migration, creation, and dissolution of firms for future years. Georeferenced National Establishment Time-Series (NETS) data were purchased by MAG and used for the firm synthesis model development. The focus of the MAG firm synthesis model is on studying the three lifecycle events of the establishment beginning with birth, relocation, and death of the establishment in the study area. First, birth of an establishment 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. Second, relocation is defined as change in address (or physical location) from one location to another. Finally, establishment death is defined as the last year in which the establishment and its internal attributes were recorded in the panel from 1990 to 2012. The model does not include businesses that were either formed or closed outside of the study area. Furthermore, business establishments were classified based on the two-digit NAICS codes to make the analysis tractable.
- **Supply Chain and Supplier-Selection Model**. Allocates commodities from producing establishments to those that need them. Establishments include those within the MAG/PAG megaregion and outside the region. The approach used in this model is an agent-based computation economics method that captures buyers' choices and suppliers' decisions relevant to buying and selling commodities. The model uses an algorithm that produces optimal and stable market allocations. The enumeration of establishments, calculation of production and consumption rates, and preparation of the supplier and buyer establishments data were developed in R. The supplier-selection algorithm was developed in Java.
- **Transport, Mode, and Path Choice Model.** Evaluates mode and shipment-size options jointly for each buyer-supplier partnership. A disaggregate joint model of mode choice and shipment size was estimated using the CFS 2012 Microdata sample as the primary source. Information on annual flows, including the origin, destination, and SCTG code of the shipment is obtained from the Supplier-Selection model. The path choice model evaluates options for breaking down the annual flows into individual shipments that are generated regularly throughout a typical year.
- **Tour-Based Truck Model.** Develops truck trip chains sorted by industry sector and by truck type. These truck trip chains are then grouped into the major linkages based on land uses 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 of stops. Truck tours are modeled through a sequence of models, including 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. ATRI truck GPS data was used for the development of heavy truck tour models and a similar dataset for light and medium trucks was acquired from StreetLight.

- **Vehicle-Type Choice Model.** Employs a logit model using the data from the 2016 commercial establishment survey to predict the usage of heavy versus medium weight trucks by establishments in the MAG region. This survey collected data at 416 establishments in the MAG region.
- **Assignment.** Outputs annual commodity flows in tons by commodity group that require integration with the rest of the model system. From a highway assignment standpoint, only the truck flows from the supply chain model are used while rail, water, and other modes of freight are not assigned to any networks. The truck flows are converted to daily truck tours and trips and integrated with the highway assignment model.

Market Segmentation (Industry, Commodity, Mode, Vehicle Type, Temporal, Activity Type)

Forty-two classes of commodities based on the SCTG were considered in this model (with the exception of SCTG 42 - Miscellaneous Transported Products). Each class of commodity is considered as an independent economic market for which supply chains were determined. MAG staff developed Standard Transportation Commodity Code to SCTG crosswalk for two-digit codes to use the TRANSEARCH data for comparing the supply chain model output (including mode choice model) which were developed using the FAF data. The NAICS system is used for determining the industry class in the firm synthesis and supply chain models. Trip assignment of the truck trips was completed 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.

Modeled Performance Measures

The performance measures that are modeled in the MAG freight model are mostly the traditional performance measures along with some indicators from the supply chain model:

- Tonnage by mode (mode share).
- Truck volume.
- Trip tables by truck type, time period, and user class.
- Truck VMT.
- Truck VHT.
- Establishments, by NAICS code.
- Producing tour statistics.
- Employment, by NAICS code.

Approach to Forecasting

The approach to forecasting and model development were based on a few main methodological principles:

1. Development of an agent-based model that will implement a micro-simulation approach to the freight system modeling in MAG region, including synthesis of establishments, disaggregation of relevant demo-economic data in the region, formation of supply-chain and establishment interaction models and tour-based travel models.

2. Development of a multi-modal freight model at least for major commodities relevant for the MAG-PAG mega-region based on commodity-based analysis of freight flows. High concentration of commodities and relatively limited number of large trip generators in the megaregion contribute to feasibility of this approach in order to capture main freight travel patterns. By providing an in-depth look at each segment of the industry it will be possible to better understand the drivers of each industry and model them specifically.

3. Behavioral approach to the model development, including modeling of the economic behaviors of establishments, shippers and carriers in generation of travel and tour formations. Examples of a freight agent's behavior can include the reaction of supply chains to variations in fuel price, global sourcing and manufacturing decisions and technology changes. The model can assist in coordinated policy development and can be an effective tool for improving freight operations.

4. Consideration of the MAG activity-based passenger modeling framework in order to facilitate future integration of the models. Model structure at this stage is envisioned including such major components as establishment synthesis, establishment interaction model, mode choice model and tour formation model.

5. Industry Specific – The model should be based in explanatory variables specific to each industry, which allows for industry related people to have a better understanding of the model and provide directly applicable data and feedback.

Types of Applications and Procedures

MAG uses its regional truck model for air quality conformity analysis, analysis of O-D patterns, bottlenecks, and infrastructure and land-use scenarios. MAG uses its freight model for forecasting. The newly developed megaregional freight model is tailored for more advanced analysis of economic policies and economic scenarios, including scenarios developed for areas that are outside of MAG's region but that affect its regional economy and freight flows. MAG planners (particularly the freight planning group) require freight model outputs. These outputs are also required by the MAG air quality division, MAG member agencies, and MAG member agency consultants. MAG also has commodity flow data—including TRANSEARCH data—at the TAZ level. MAG has used these data for future-year commodity flow forecasts, validation and calibration of freight models.

Data

Geographic Scope

The MAG freight model simulates freight shipments to, from, and within the Arizona Sun Corridor megaregion, which covers the Phoenix and Tucson Metropolitan areas in Maricopa, Pima, and Pinal counties. This region is home to more than 80% of the State's residents. Figure 22 shows the extent of the Sun Corridor megaregion.

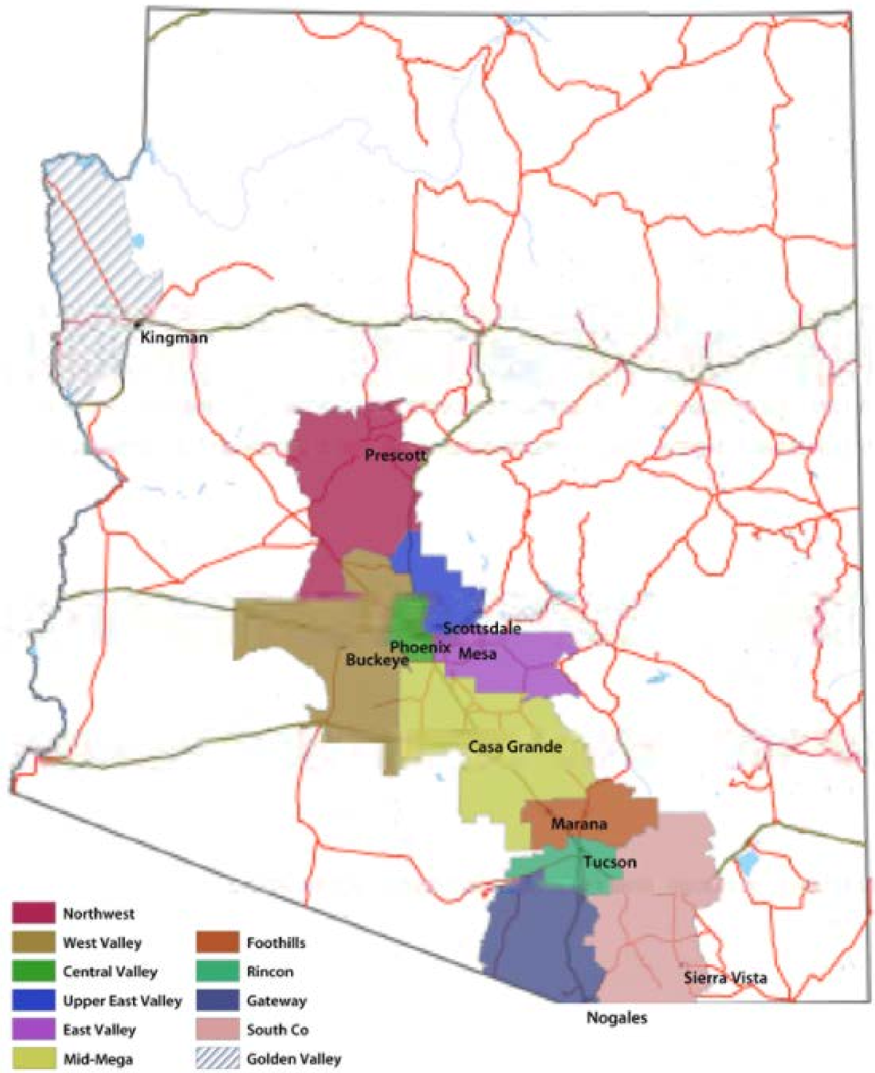

Figure 22. Sun Corridor Megaregion.
Source: (Maricopa Association of Governments, 2017)

The model focuses on regional commodity flows to/from/within MAG/PAG region. However, a variable zone system was used for the framework, which comprises finer zones in the Sun Corridor for more detailed analysis and larger zones for the external areas to Sun Corridor. The zone system includes TAZs in the MAG/PAG region, counties in the rest of Arizona, and FAF zones for the rest of the country. Figure 23 shows the zone system used in this model.

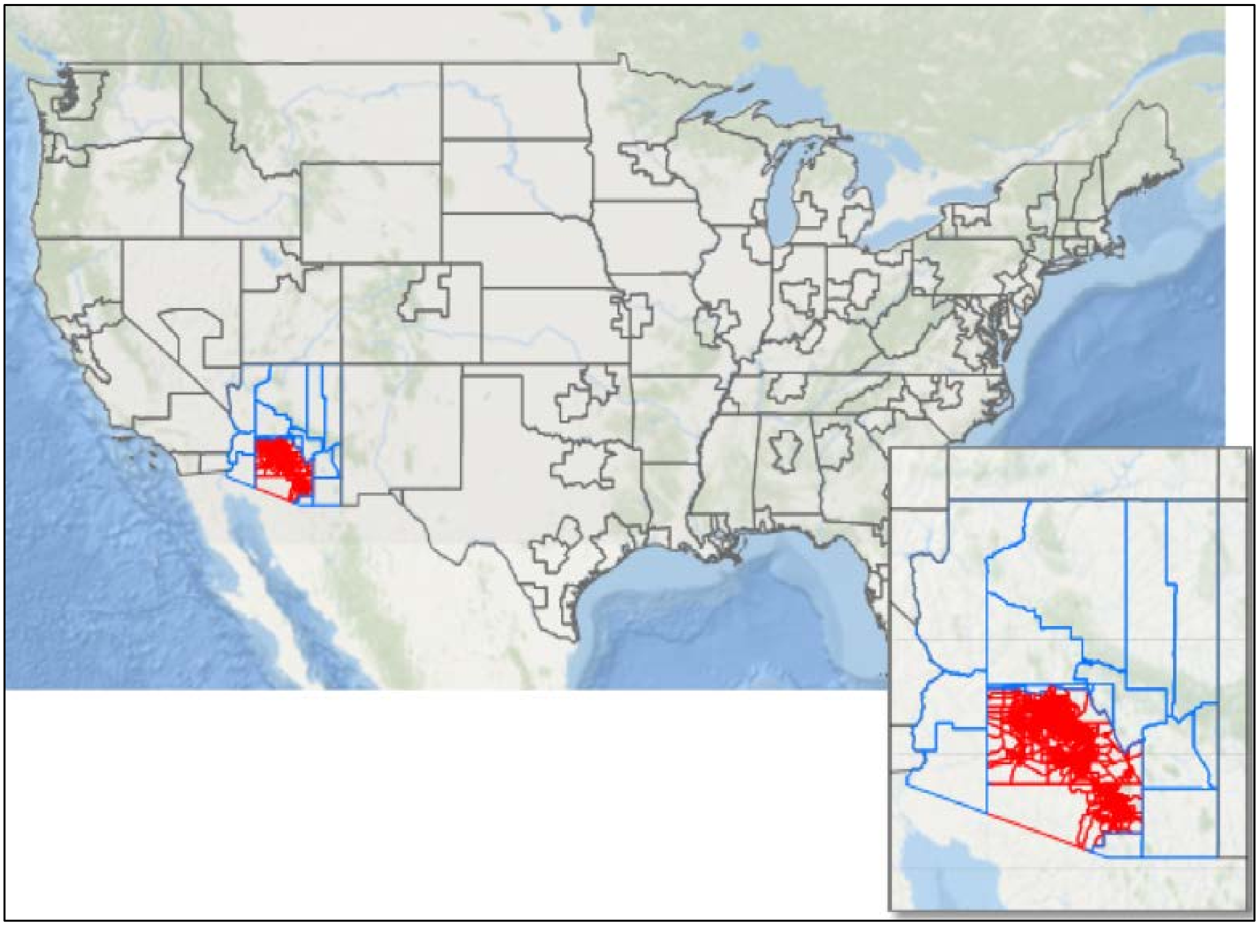

Figure 23. MAG Freight Model Zone System.
Source: (Maricopa Association of Governments, 2017)

Data Inputs

Firm Synthesis model utilized the following main datasets:

- NETS data.
- Employment data from CBP was used to generate establishments external to the Sun Corridor megaregion and to estimate industry-specific input and output factors. Firm synthesizer output was used to classify supplier and buyer agents in the megaregion area.
- MAG-PAG socio-economic data that includes regional population and employment.

The Supplier Selection Model used the following main datasets:

- Regional Make and Use Tables from Impact Analysis for Planning (IMPLAN[3]). Regional Make and Use tables were used to calculate regional production and consumption rates by industry class per employee for all establishments in the megaregion.
- FAF4.1 data.
- IHS Global Insight's TRANSEARCH data.
- CFS 2012 Microdata for Arizona.
- MAG Regional Establishment Survey data.
- BEA IO Accounts tables, which contain Make and Use amounts of exchanged commodities between industries (at the six-digit NAICS level) were used to calculate amount of commodity produced and consumed on average per employee in each industry class for establishments outside the megaregion.
- National average and region—specific commodity prices derived from the FAF4.1 and Arizona-based sample of CFS PUM.
- A crosswalk was developed between FAF External Regions and MAG/PAG External stations to convert the foreign origin of a supply chain to MAG/PAG external station.
- Two Commodity-Industry Crosswalks that provide mapping between industries classes (six-digit NAICS and BEA IO industry classes) and the associated commodities (two-digit SCTG). These crosswalks were developed using the detailed description of SCTG and NAICS codes provided by U.S. Census Bureau and a preliminary commodity-industry bridge used in FAF data.
- BEA correspondence table that links BEA IO industry classes to NAICS six-digit industry classes.
- Aggregated inbound and outbound commodity flows at FAF-zone level derived from FAF4.1 data and used to calibrate estimated production and consumption amounts at establishment-level.
- GCD matrix calculated using the zoning system in the geographic information system (GIS) software.

The transport, mode, and path choice models were developed using the following main data sources:

- CFS 2012 microdata sample (the model development process used Arizona-based shipments).
- Multimodal transportation levels of service (developed by MAG): travel times, distances, logistics handling nodes (e.g., intermodal terminals and air cargo terminals), and number of rail tracks used (i.e., by track owner).

[3] IMPLAN is a proprietary data source and includes data on employment, economic output for commodity categories, input-output data, and transportation spending, by industry.

- Transportation costs for truck (less-than-truckload and truckload), rail, air, and parcel. This information is based primarily on BTS data and supplemented by rates found online.

The tour-based truck model development process used the following main data sources:

- ATRI truck GPS data. Maricopa Council of Governments (MAG) obtained samples from four different months.
- Streetlight data. Medium and Light Truck Tour models were developed using data from this vendor. MAG obtained data for April 2015.
- Land-use categories in Maricopa County, Pinal County and Pima County were different. MAG Truck model utilizes ten land uses. Hence, cross-walk tables were developed for each county, reconciling their land-use types with the ones referenced in MAG truck model, to facilitate Truck GPS data analysis.
- A crosswalk was developed between the Tour Type and Tour Purposes in Supply Chain and Truck Tour Models.
- Maricopa Council of –Pima Association of Governments socio-economic data that includes regional population and employment.
- VIUS uses product classes similar to the commodity classes used in the CFS or FAF or TRANSEARCH. The payload factors by each truck type and Standard Classification of Transported Goods (SCTG) commodity were developed from the Arizona records in the 2002 VIUS database.
- Regional PM Peak skims.

Vehicle choice truck model development process used the following main data sources:

- 2016 MAG commercial establishment survey.

The process of developing independent networks for all main transportation modes that operate in Arizona used the following data sources:

- MAG modeling network.
- PAG modeling network.
- FAF3 roadway network.
- NTAD rail network.
- NTAD rail yards database.
- [OpenFlights.org airport, airline, and route data](https://openflights.org/data.html) (enumerated web address: https://openflights.org/data.html).
- U.S. BTS T100 segments database.
- MAG performed detailed analysis of the available freight data. The report on this research effort and detailed information about the datasets utilized for the model development are available from the MAG website.

Data Used for Estimating Model Parameters

MAG utilized NETS data from 1991 to 2011 for estimating establishment birth rates by industry type. CFS, Public Use Microdata (PUM) was used to estimate parameters in the transport, mode, and path choice model. ATRI and Streetlight data was used for estimating truck tour models. The unit value of commodities was asserted from FAF data. The supplier evaluation criteria were drawn from FAF (cost), synthesized firms (quality, reliability), network skims (delivery), and the GIS shapefile of zone system (distance). The transportation costs used in path choice model development were asserted from various sources like USDOT's Research and Innovative Technology Administration, among others.

Data Used for Model Calibration

The calibration of the model included calibration of the supplier-selection model and calibration of the mode choice model. FAF4.1 data was the main data source for calibration of both models. FAF4.1 commodity flow patterns to, from, and within MAG/PAG region were used for calibration of the supplier-selection model and the modal split in the FAF4.1 data was used for calibration of the mode choice model. The regional TRANSEARCH data sample was also considered and analyzed for the model calibration. However, it was not selected for the final calibration due to several inconsistencies that were found between TRANSEARCH and FAF data.

Data Used for Model Validation

The portion of NETS data that is left out of estimation is used to validate the model. This smaller set comprised 20% of the establishments that were randomly selected to avoid introducing bias into either set. Also, MAG desired a sufficient and comprehensive supplier-selection information (an establishment survey can gather that data) but it was not available. The survey questions should be focused on gathering information on the supplier-selection process, such as the scoring process by establishments of different sizes and industries. InfoGroup data and the Maricopa County Employer Database were also utilized in validating the output from Firm Synthesis model.

The assignment validation is done at two levels of geography. Screenlines analysis includes some of the major freeways that pass through the region and carry a large volume of trucks in the region.

Data Desired, but not Found

Data on the intermediate logistics nodes (e.g., consolidation centers, distribution centers) was desired but not available. The shipping chain choice could not be determined for truck shipments without these data. Instead, truck volumes were validated against observed count data. Lack of behavioral data on carriers, shippers, buyers, and suppliers effected the choice of the model methodologies.

Detailed information about the model and the freight datasets is available online at the following websites:

- Final Report for MAG Next Generation Freight Demand Model (enumerated web address: http://www.azmag.gov/Portals/0/Documents/TRANS_2017-02-13_SHRP2-C20-MAG-Next-Generation-Freight-Demand-Model-Update.pdf?ver=2017-04-06-112009-200).
- Review of Freight Data Sources for the Development of a Behavior-Based Freight Model (enumerated web address: http://www.azmag.gov/Portals/0/Documents/TRANS_2016-06-01_Review-of-Freight-Data-Sources-for-the-Development-of-a-BehaviorBased-Freight-Model.pdf?ver=2017-04-06-112000-513).

OREGON STATEWIDE

Methodology

Oregon's economy is growing faster than the national rate. Despite this growth, the Oregon Department of Transportation (ODOT) has only modestly increased the capacity of their State's highway system to meet growing demand over the last 20 years. Traffic congestion is rising quickly, affecting passenger travel and freight movement alike. Reliability is also declining while transportation infrastructure is aging, and revenue streams are shrinking. Oregon is an export-dependent State, relying heavily on the transportation system to get goods to market via highway, rail, water, and air. When transportation costs rise, Oregon's jobs and products are affected. Questions related to the trade-off associated with investing and disinvesting in the Oregon transportation system have been explored using the Oregon Statewide Integrated Model (SWIM). SWIM is one of the several tools and methods used to answer these questions. SWIM can also be used to estimate commodity flows, which is valuable to decision-makers and important to understanding regional economies and how they rely on the transportation system. ODOT has recently completed the development of the latest version of SWIM (version 2.5). Previous versions of the model (SWIM 1.0 and SWIM 2.0) are now retired and not being used by ODOT.

Supply Chain Modeling Needs

ODOT developed SWIM to evaluate the impact of actions related to transportation at the statewide level. Representing the fundamental economic forces influencing transportation and land-use activity was paramount in the model design. The supply chain modeling simulated how commodities are moved as freight by different modes of transport, such as marine, rail, and truck for a typical weekday. For trucks, shipments are simulated to appropriately transport daily commodity shipments modeled by the business activity allocation module of SWIM. ODOT has used this tool to evaluate the impacts of weight restricting bridges, recovering from a major earthquake, planning to meet the future demands on the system while facing aging infrastructure, and shrinking funding streams. SWIM has also been used to evaluate the uncertainty associated with economic growth and external shocks, such as rising fuel costs.

ODOT uses its integrated land-use transport economic model to answer the following policy, investment, and project assessments related questions:

- Where are the trucks coming from and going to—locations within Oregon or outside of the State?

- How does truck volume or routing change based on the socioeconomic characteristics of an area or the freight facilities available?

Model Structure, Component Interactions, and Segmentation

SWIM is an integrated economic land-use transport model covering the entire State of Oregon. SWIM system represents the behavior of the economy, land-use, and transport system in the State of Oregon and the interactions between them. The system is composed of a set of interconnected components that simulate different aspects of the full system. The structure of the overall model is shown in Figure 24. The following components are related to freight and commercial vehicle movements:

- **The New Economics and Demographics (NED) component**. Determines model-wide production activity levels, employment, and imports and exports based upon official Oregon State forecasts.
- **The Activity Allocation (AA) component**. Determines commodity (goods, services, floorspace, labor) quantity and price in all exchange zones to clear markets, including the location of business and households by beta zone.
- **The Commercial Transport (CT) component**. Generates mode split for goods movement flows and generates truck trips, combining shipments and possible trans-shipment locations, for a typical weekday. The CT module is written in the R statistical language.
- **The External Transport (ET) component**. Generates truck trips from through movements based on external station growth rates.
- **The VISUM platform.**[4] Assigns trips to a computer representation of the statewide transportation network, trips generated in the Person Travel (PT) Model and CT Model, generating routes with distance and travel time information.

[4] The VISUM Platform (enumerated web address: http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/).

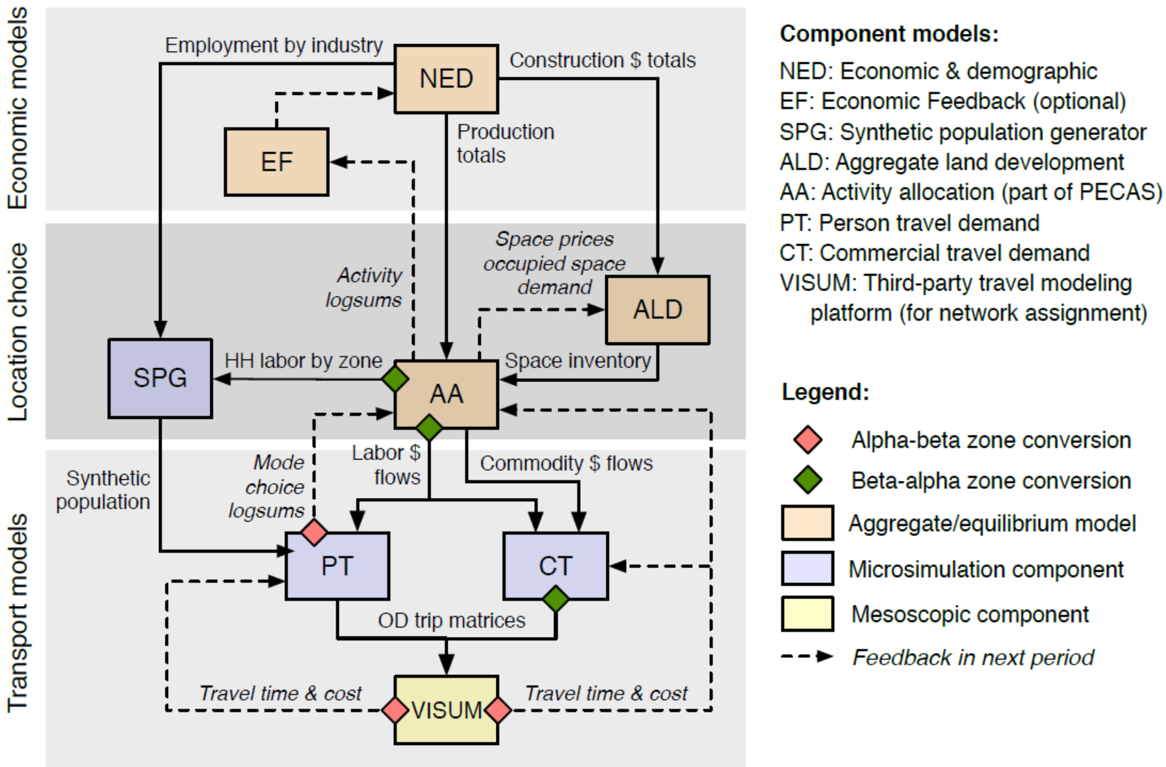

Figure 24. SWIM Overall Model Structure.
Source: (WSP, ECONorthwest, HBA Specto and RSG, 2017)

The model steps through time in one-year intervals, typically to a 20-year forecast horizon. The CT module is a hybrid framework that includes both aggregate and microsimulated data and models. The CT module includes several important dynamics unique to commercial vehicle travel:

- Represents explicit interaction with macroeconomic (NED) and AA modules.
- Represents supply chain linkages.
- Represents the complex structure of urban truck tours.
- Recognizes the large variances associated with freight activities.
- Integrates with the FHWA FAF.

Market Segmentation (Industry, Commodity, Mode, Vehicle Type, Temporal, Activity Type)

The commodities produced and consumed in the model, including model area imports and exports, are tracked in the AA and CT components, including 39 types of goods based on the SCTG categories. Some commodity groups are combined to eliminate small commodity flows and simplify the model. The various modes and vehicles used in the model to transport goods flows are shown in Table 8. Non-truck freight modes are not assigned to the network.

Table 8. SWIM Transport modes and vehicle types.

Code	Trip Mode	Definition	Component(s)
TRK1	Truck type 1	<34,000 lbs. (likely single-unit)	CT, ET
TRK2	Truck type 2	34,000–64,000 lbs.	CT, ET
TRK3	Truck type 3	64,000–80,000 lbs. (articulated)	CT, ET
TRK4	Truck type 4	80,000–105,500 lbs. (articulated)	CT, ET
TRK5	Truck type 5	>105,500 lbs. (articulated)	CT, ET
SAA	Air freight	Air freight (not assigned)	N/A
SRR	Rail freight	Rail freight (not assigned)	N/A
SWA	Waterborne freight	Waterborne freight (not assigned)	N/A

Source: (WSP, ECONorthwest, HBA Specto and RSG, 2017)

The industries defined in the NED and AA modules were built from data classified using different systems. IMPLAN data industries and NAICS code industries are used in these modules. Employment is forecast by IMPLAN sector (440 sectors) using a crosswalk and consistent with the official State economic forecast.

Modeled Performance Measures

ODOT does not use SWIM to generate performance measures, but metrics are developed to meet needs of specific analysis projects from SWIM. The metrics that are modeled and reported in SWIM and are used as part of the measures to analyze policy questions depends on the reliability of the input data that is accessible for each analysis project and on the purpose of the application. Some of the metrics that SWIM produces include:

- Average annual daily traffic.
- Regional share of Oregon Gross State Product.

Approach to Forecasting

The SWIM system runs on a dedicated multiprocessor personal computer. The modeling system is run using a Python script, which is called using a DOS command window to automatically set up the required directory structure. The script calls each component module, and runs the model through time. Each run of the model has its own base scenario directory structure that is a complete reference scenario run and stores full model outputs. The model steps through time in one-year intervals, typically to a 20-year forecast horizon. The NED model provides the starting point with the economic forecast information built from external data and forecasts from the State revenue forecast. The NED module provides model-wide production activity levels, employment, imports, and exports based upon the long-range forecasts consistent with the Department of Administrative Services' Oregon Economic & Revenue Forecast and the associated baseline macroeconomic forecast from IHS Markit. NED provides the starting point for the population synthesizer, AA module, land-use model, and PT and CT model to simulate people and business activity.

The CT module represents the flow of goods within the SWIM modeled area. It is designed to work closely with the AA module and complement the PT module. The current version of CT is written in the R statistical language, which is widely used at ODOT. Many of the models in the CT module are implemented as parallel processes using the doParallel package in R. The CT module reads the outputs produced by other modules and its own configuration and parameter files. Its output is a list of discrete truck trips and aggregate flows by commodity and mode. The CT program runs in 10–20 minutes, depending upon the number of cores and processor speeds.

Types of Applications and Procedures

SWIM has often been used to evaluate the economic effects of different investment scenarios. Modeling work completed to date includes evaluating the effects of weight-restricting bridges on heavy trucks, recovering from a major seismic event, impacts of higher vehicle operating costs and evaluating future investment options as infrastructure ages, construction costs rise, and funding streams shrink.

Data

Geographic Scope

SWIM operates at two geographic levels within the modeled area, which is shown in Figure 25. Both geographic levels encompass 36 counties within Oregon and 39 counties in adjacent states. The latter is commonly referred to as the model's halo area. The halo encompasses a roughly 50-mile buffer around Oregon comprising 39 counties in Washington, Idaho, Nevada, and California. A system of 2,950 alpha zones (light and dark lines in Figure 25) is the most disaggregate zone system. These include 12 external stations, shown in Figure 25. These external stations serve as gateways to the six world markets used to represent the world beyond the halo. The six world markets link to the model transport network at the 12 external stations.

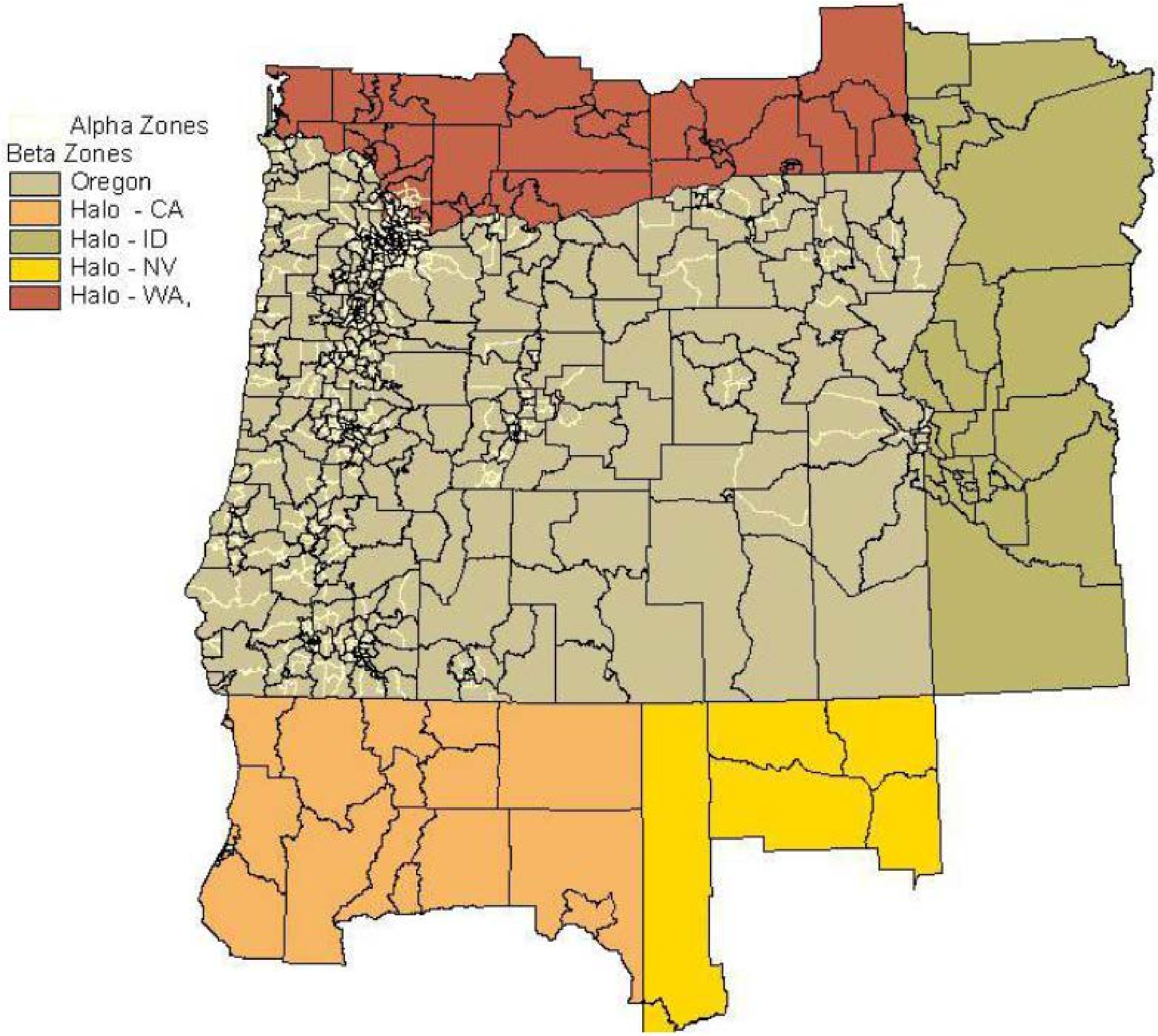

Figure 25. SWIM modeled area zone system.
Source: (WSP, ECONorthwest, HBA Specto and RSG, 2017)

SWIM represents the world outside of Oregon by FAF regions, which are aggregations of counties within the United States and countries or world regions outside of it. Within Oregon, the CT module operates at the alpha zone level. Because only Oregon and the halo are represented in the SWIM network, the interstate flows generated by CT module are routed through the external gateways.

Data Inputs

ODOT acquired and utilized the following datasets to develop the statewide supply chain freight model:

- CFS data (both publicly available and microdata).

- FAF data.
- IO Make and Use tables (BEA).
- VIUS data.
- Foreign trade statistics compiled by the U.S. Department of Commerce.
- Carload Waybill Sample (Surface Transportation Board).
- U.S. Army Corps of Engineers Waterborne Commerce data.
- BTS T100 segments air freight movement database.

The current version of CT relies heavily upon the FAF to depict long-distance freight flows.

Data Used for Estimating Model Parameters

SWIM used the following main data sources for estimating model parameters:

- CFS data.
- FAF data (to disaggregate FAF flows to smaller zones within a FAF region).
- VIUS data.

Data Used for Model Calibration/Validation

SWIM used the following main data sources for model calibration/validation:

- FAF4.
- ODOT traffic counts.
- Urban truck surveys from Denver, Houston, Ohio, Sydney, and Ontario.
- HERE data.[5]
- State and Portland CFSs.
- Information provided by stakeholders (this includes validation of truck routes patterns, industry employment locations, detour routes, and other local knowledge).

Data Desired, but not Found

Truck commodity flows by highway were the main data desired, but these data were unavailable.

Detailed information about the model and the freight datasets is available online at the following website:

- SWIM Version 2.5 Model Development Report (enumerated web address: http://www.oregon.gov/ODOT/Planning/Documents/Statewide-Integrated-Model-Vers2-5.pdf).

[5] HERE Data (enumerated web address: https://here.com/en/products-services/map-content/here-map-data).

MARYLAND STATEWIDE/BALTIMORE REGION

Methodology

The Maryland State Highway Administration (SHA) and Baltimore Metropolitan Council (BMC) model is a two-agency freight model developed as part of the Freight and Commercial Vehicle Model Development project. The model work was completed in part with funding provided to SHA and BMC by FHWA under a SHRP2 C20 Implementation Assistance Program grant. The SHA/BMC model comprises two major components that function at different geographical scales. The larger, national-scale model that is designed for integration with the Maryland Statewide Model (MSTM) maintained by SHA is a supply chain model that simulates the transport of freight between supplier and buyer businesses in the United States, focusing on movements that include Maryland. As with the FreightSIM model of Florida on which it is based, the supply chain model produces a list of commodity shipments sorted by mode and converts those to daily truck trip tables that can be assigned to the national and statewide networks in MSTM along with trip tables from the passenger model component of MSTM. The second major component of the SHA/BMC freight model is a truck-touring model of the Baltimore modeling region, a 10-county area of Maryland. This regional portion of the model is a truck-touring model that simulates both freight trucks (using the supply chain model's shipment list as a demand input) and nonfreight commercial vehicles (using demand generated independently of the supply chain model).

Supply Chain Modeling Needs

SHA and BMC's application for the SHRP2 C20 grant outlined the planning needs that the SHA/BMC model is intended to support and was used to inform the development of the supply chain model. The agencies sought to develop modeling tools that provided some understanding of the connections between the region's economy, the resulting demand for freight movement, and the performance of the transportation systems. Three objectives informed the design of the model and supply chain modeling concepts:

- Agency needs for information on transportation system performance, with an emphasis on the role of freight movement and its role in the economic growth of the Baltimore region, Maryland, and the United States.
- The complexity of the regional transportation system—Maryland's position in the densely populated eastern seaboard and the congested Baltimore-Washington metropolitan region—increases the challenges of modeling freight movement.
- The desire to model long-distance truck movements, empty truck movements, local freight distribution, the effects of port expansions, and improvements to intermodal facilities.

The SHA/BMC model's design is a joint supply chain and truck-touring model where freight flows to and from the region influence vehicle movements at the local level to provide the desired modeling connections. For example, changes over time in the freight flows to and from a region influence the demand for long-distance truck travel and influence the need for additional local truck movements to facilitate local deliveries and pick-ups of shipments. The SHA/BMC model's geographical extent was designed to capture the full influence of the supply chains of shipments to and from the region. This model represents business establishments across the country and global suppliers and buyers who produce imports and consume exports. The model structure supports scenario testing to understand the effects of changes in the economy over time, including different patterns of long-haul domestic flows and imports and exports as domestic and international trading partners change.

Model Structure, Component Interactions, and Segmentation

The SHA/BMC model includes a national supply chain model (NSCM) and an urban truck-touring model, including the freight truck-touring model (FTTM) for freight and the commercial vehicle touring model (CVTM) for non-freight-carrying trucks. Figure 26 shows the overall model system used by SHA and BMC, which includes both the MSTM maintained by SHA and BMC's regional travel demand model. Both models contain passenger travel demand models that are used to estimate personal travel by auto and other modes. The components of the freight model are shared between the SHA and BMC models; the approach to integration between the two models is discussed below.

The NSCM comprises a firm synthesis model and a supply chain model. The NSCM simulates the transport of freight between supplier and buyer businesses in the United States and prioritizes movements that include Maryland. The model uses the output, a list of commodity shipments by mode, in two ways. First, in the MSTM, a model component connected to the NSCM converts the annual shipment flows to daily vehicle trip tables that can be assigned to the national and statewide networks in the MSTM along with trips tables from the passenger model. Second, the list of commodity shipments sorted by mode is used as an input to the FTTM in BMC's regional travel demand model.

The FTTM simulates truck movements within the Baltimore region that deliver and pick up freight shipments at business establishments. The FTTM is a tour-based model and builds a set of truck tours. These tours include transfer points at which the shipment is handled before delivery/after pick up for shipments with a more complex supply chain (i.e., a warehouse, distribution center, or consolidation center) and the suppliers and buyer of shipments where those are within the model region. The shipment list from the NSCM is used as the demand input for the FTTM and describes the magnitude and location of delivery and pick-up activity in the region that must be connected by truck movements. The model generates trip lists by truck type and time of day so that the outputs from this model can be combined with the outputs from the CVTM and appropriate passenger vehicle trip tables for highway assignment.

The CVTM simulates the remainder of the travel of light, medium, and heavy trucks for commercial service purposes (i.e., providing services and goods delivery to households and services to businesses). Like FTTM, the CVTM is a tour-based model, but demand is derived from the characteristics of the business establishments and households in the region and is not affected by the supply chain model. CVTM simulates truck and light-duty vehicle movements based on demand for services and goods from certain industries while FTTM simulates truck tours based on commodity flows.

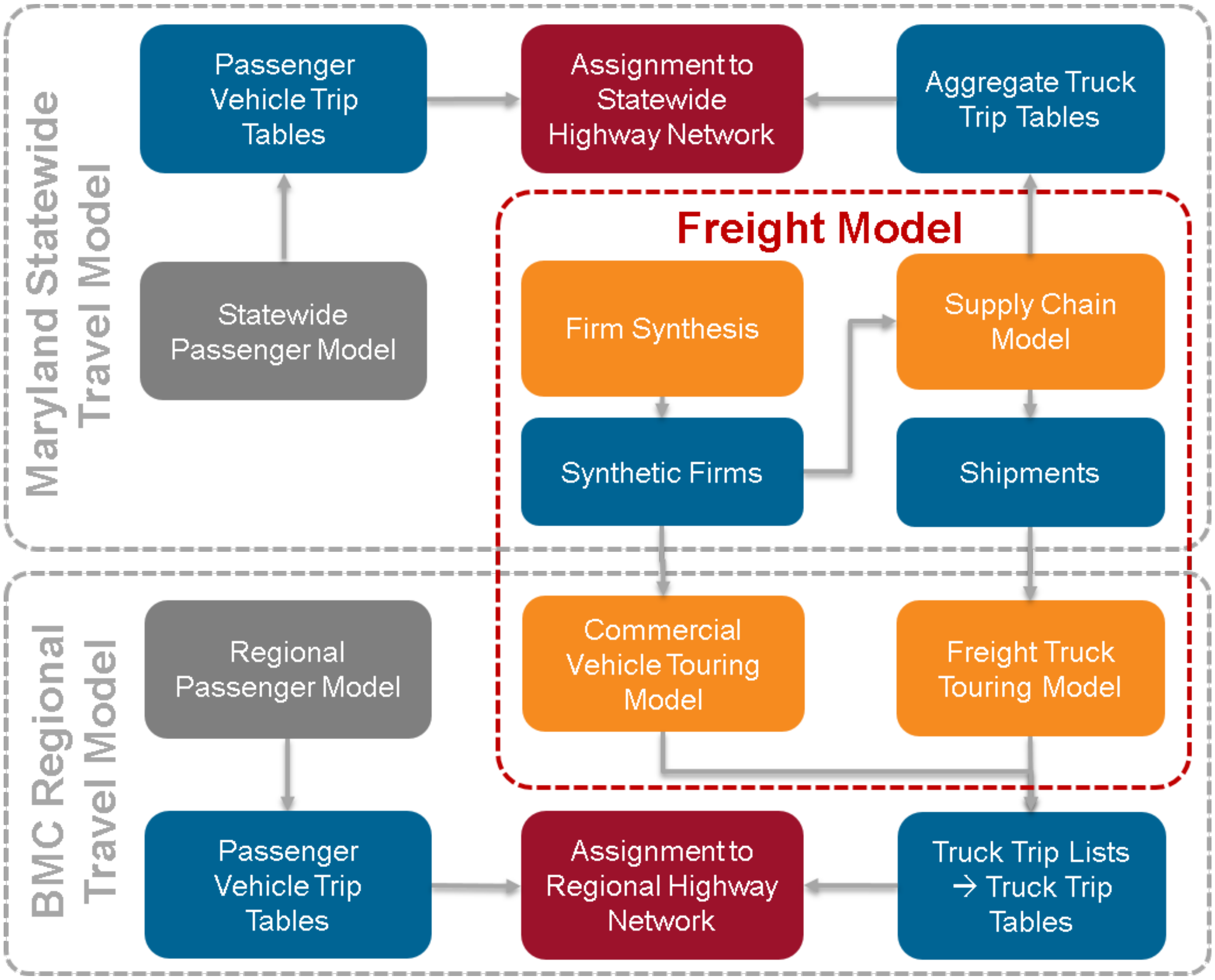

Figure 26. MSTM and BMC Model System.

Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

The NSCM includes components that synthesize business locations, trading relationships between businesses, and the resulting commodity flows, distribution channel, shipment size, and mode and path choice for each shipment made annually. A flow chart of the NSCM is shown in Figure 27. The transport and logistics chain models produce a list of shipments that are ready for extraction for use in the regional truck-touring model. This output is also converted into number of vehicles and loads ready for modal assignment (in this case, assignment is done for all truck trips to the highway network, to produce outputs of trucks volumes on the highway network, including to and from transfer facilities). The components shown in the flow chart perform the following model steps as part of firm synthesis and supply chain modeling:

Firm Synthesis

1. **Business Establishment Synthesis**. Synthesizes all business establishments in the United States and a sample of international business establishments using input employment data, which is more spatially detailed for the modeled region and less detailed for the rest of the United States; includes growth factors for future-year business synthesis.

2. **Annual Production**. Characterizes annual production by business establishments based on industrial classification.

3. **Annual Consumption**. Characterizes annual consumption by business establishments through relationships described in the IO data that describe the input commodities required to produce commodities.

Supply Chain Model

1. **Buyer-Seller Matching**. Selects supplier establishments for each buyer establishment by type, choosing one for each commodity input required by the buyer establishment.

2. **Commodity Flow Allocation**. Predicts the annual demand in tonnage for shipments of each commodity type between each establishment in the United States using input commodity flow forecasts.

3. **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).

4. **Shipment Size and Frequency**. Estimates discrete shipments delivered from the supplier to the buyer.

5. **Modes and Transfers**. Predicts four primary modes (road, rail, air, and waterway) and transfer locations for shipments with complex supply chains using inputs from modal networks, including descriptions of transfer facilities.

6. **Multimodal Network Flows**. Produces a **list of shipments** for the transport and logistics chain model that are ready for extraction for use in the regional truck-touring model. This output is also converted into number of **vehicles and loads** ready for **modal assignment** (in this case, assignment is done for all truck trips to the highway network, to produce outputs of trucks volumes on the highway network, including to and from transfer facilities).

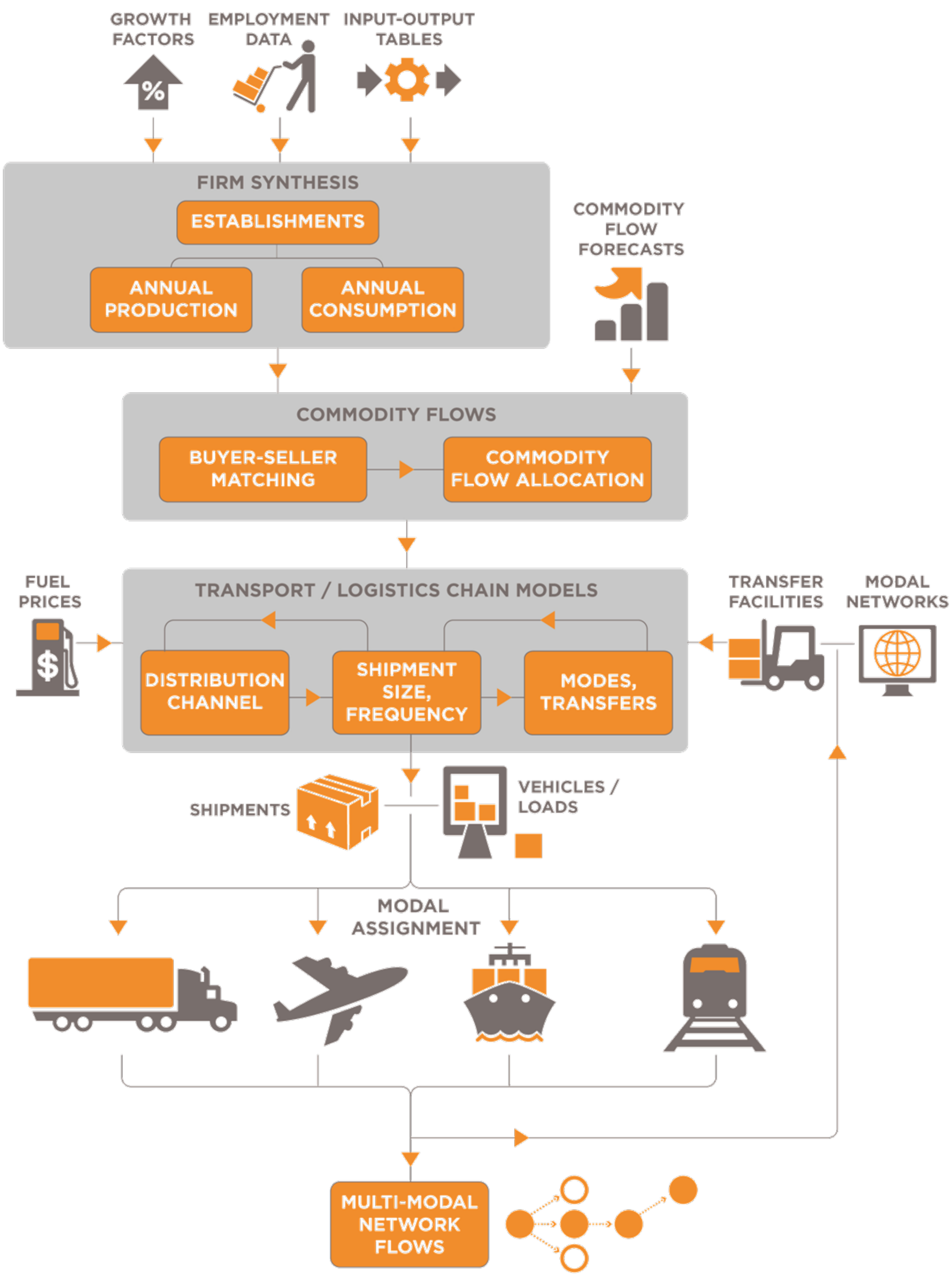

Figure 27. Components of the Supply Chain Model, SHA/BMC Model.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

Market Segmentation (Industry, Commodity, Mode, Vehicle Type, Temporal, Activity Type)

The SHA/BMC model system represents two major market segments for truck travel demand: freight movement and nonfreight commercial vehicle movement to provide services. The freight portion of the model—comprising the firm synthesis, supply chain model, and FTTM—contains several types of market segmentation depending on the unit of analysis of each model component.

The firm synthesis model characterizes business establishments by location (TAZ), establishment size (eight employment categories ranging from 1–19 employees to over 5,000 employees) and industry (six-digit Census Bureau NAICS categories). The number, type, and size of business establishments is controlled at the TAZ level within Maryland using the regional employment forecast data, which are grouped into seven employment categories that are aggregations of NAICS categories (i.e., retail, office, industrial, education, health services, food service, and other services). The commodity production and consumption by business establishment uses the BEA's six-digit NAICS categories (which is slightly aggregated in comparison to the U.S. Census Bureau's NAICS categories used for the industrial classification of the business establishments).

The supply chain model works with FAF commodity flow data and uses the 43 Standard Classification of Transported Goods categories for segmentation of shipment commodity. The distribution channel of the shipment flow through the supply chain is segmented into direct shipments, and those use one, two, or three transfers at distribution centers or intermodal transshipment locations. The supply chain model allocates shipments into size categories using a two-stage process, ultimately calibrating the distribution to the nine shipment-size categories, ranging from less than 50 pounds to more the 100,000 pounds used by the CFS. The shipments are allocated to one of four main modes (truck, rail, water, or air), with the intermodal paths being some combination of those modes (e.g., truck-rail-truck). The conversion to trip tables in the aggregate outputs from the supply chain model uses truck percentages for light, medium, and heavy trucks (FHWA class 2–3, 4–7, and 8–13, respectively). The trip tables are divided into four time-period-specific trip tables (AM peak, midday off-peak, PM peak, and nighttime off-peak) using fixed factors.

The truck-touring model in the SHA/BMC model uses the same vehicle-type categories (light, medium, and heavy trucks) as the supply chain model's aggregate trip table outputs. The output trip roster from the truck-touring model has trip start and end times defined by minute of the day. These can be aggregated as needed into time period trip tables for static assignment. The stops that trucks make in the region are segmented into a series of different activity types. Scheduled stop activities (i.e., those where the truck is conducting its primary business) include delivery of a shipment, pick-up of a shipment, service activity, and meeting (with the latter two only relevant for nonfreight commercial vehicles). The model also adds intermediate stops for meals/breaks, vehicle service/refueling, and other purposes.

Modeled Performance Measures

The outputs from the SHA/BMC freight model include databases of business establishments, shipments by mode, and truck trips. The truck trips are aggregated into zone-to-zone trips tables and assigned to both the statewide and regional highway networks to give medium and heavy truck class volumes, by link.

The SHA/BMC freight model can produce the following performance measures from the model outputs:

- Annual tonnage shipped by mode to, from, and within Maryland, by SCTG commodity. These results are available at the TAZ level using both the statewide and regional zones (the latter is for the BMC model region).
- Mode shares of shipments by commodity and origin/destination, including imports and exports.
- Truck origin/destination patterns by truck type, activity, and time of day.
- Truck volumes by truck type, time period, and link on both the Maryland Statewide Model and BMC highway networks, which can be used to derive measures such as VMT and vehicle hours traveled (VHT) aggregated spatially by area type, functional class, and facility.

Approach to Forecasting

The SHA/BMC freight model is integrated into both the Maryland Statewide Transportation Model (MSTM) and BMC's regional travel demand model. MSTM and the BMC's regional travel demand model are loosely integrated. SHA has assumed responsibility for the NSCM integrated within their MSTM and BMC has assumed responsibility for the FTTM and CVTM models integrated within their regional travel demand model. In this loose integration, the two parts of the model will operate independently. However, the outputs from the synthetic establishments located in the BMC region and the shipments traveling into, out of, and within the BMC region will be created by the NSCM within the MSTM. These outputs will then be provided as inputs to the urban freight modeling system (FTTM and CVTM) within the BMC regional travel demand model. For forecasting future scenarios, the firm synthesis model adjusts to match the input employment data at the TAZ level.

The two agencies cooperate on employment forecasts and now use a consistent seven-category employment system, so the output business establishment database is appropriately adjusted for use in future years at both the statewide and regional level. The supply chain model's main future-year and alternative scenario inputs are commodity flow data and network inputs. By default, FAF forecasts are included as commodity flow data inputs, but the model user can adjust inputs to evaluate scenarios with alternative future commodity flows. The network inputs include forecasted changes in daily travel times and distances due to network changes (to highway, rail networks, and waterways) and to intermodal/transfer locations (e.g., rail yards, ports, airports, and truck terminals/distribution centers). The truck-touring models use the more detailed time-period-specific skims as the truck-touring models are sensitive to congested travel times by time period. As a result, forecasting in these models requires future-year scenario networks and the requirement of producing forecasted passenger trips to support joint assignment of passenger trips and truck trips.

Types of Applications and Procedures

The SHA/BMC freight model supports policy decision-making objectives, including project planning, corridor studies, and freight tolling. At the regional level, BMC staff use model simulation to support long-range plan development and federal transportation conformity determination. BMC staff use model outputs in regional transportation system performance measures of mobility, accessibility, equity, and environmental effects presented to committees. At the corridor level, performance measures of link level of service, travel speeds, and cost will be used at the project-planning level. These performance measures should be sensitive to existing and emerging transportation planning scenarios such as additional travel lanes, new interchanges, truck prohibitions, managed/electronic toll lanes, and freight generation scenarios such as port expansion or new intermodal transfer facilities.

Data

Geographic Scope

The supply chain model, which is integrated with the MSTM, has a global geographic scope. At its broadest, it represents import and export movements to and from eight international zones. Domestic movements are represented to and from the rest of the Unites States, and the model design includes simplified transportation networks that cover the entire continental United States. The model uses the MSTM TAZ, system, which is more spatially detailed in portions of the states surrounding Maryland, and then more highly detailed within the State of Maryland. Figure 28 shows the North American extent of the model's zone system, and Figure 29 shows the State of Maryland and the halo of smaller zones around the State. The national transportation networks are connected to detailed transportation networks covering Maryland. The regional freight and CVTMs cover the BMC modeling region. Figure 30 shows the BMC modeling region and the TAZ boundaries within the region.

Figure 28. SHA/BMC Model Zone System, North American Extent of MSTM Zones.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

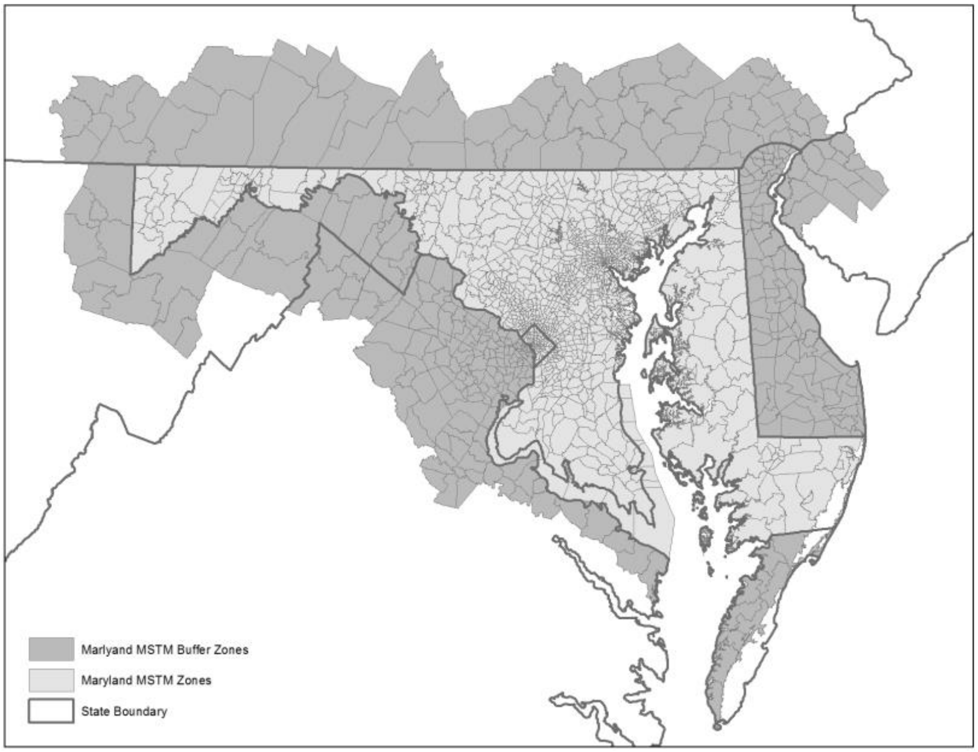

Figure 29. SHA/BMC Model Zone System, Maryland, and HALO Extent of MSTM Zones.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

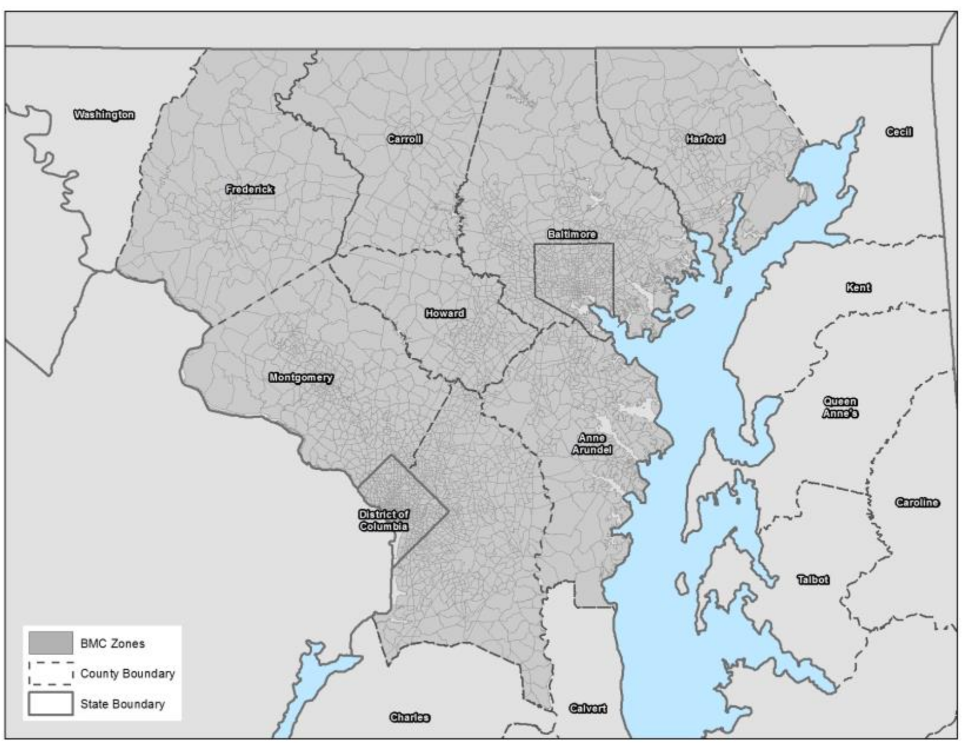

Figure 30. SHA/BMC Model Zone System, Extent of BMC Regional Zones.
Source: (RSG, University of Maryland, and Vision Engineering and Planning, 2017)

Data Inputs

The SHA/BMC models use the following main data sources as input:

- **Zone Systems**. MSTM zone system developed by SHA; combination of U.S. states and TAZs around and within Maryland; BMC regional travel model zone system developed by BMC; and county-level zone system (U.S. Census Bureau).
- **Economic Data**. IO Make and Use tables (BEA) and industry to commodity correspondences (BEA and FAME).
- **Employment Data**. CBP data (U.S. Census Bureau) and SHA and BMC employment data sorted by TAZ. LEHD data by Census block for allocation from counties to smaller geographical units.
- **Commodity Flow Data.** Commodity Flow Data from the FAF4 (FHWA).
- **Networks**. SHA's MSTM national highway network and BMC's regional travel demand model network used for highway skims and assignment. The model's nonfreight networks for rail, waterways, and the locations of ports, airports, and intermodal facilities are based on the National Transportation Atlas Database (NTAD).
- **Distribution Centers and Warehouses**. Database of the locations of distribution centers and warehouses developed from employment data with visual confirmation using Google maps.

Data Used for Estimating Model Parameters

The SHA/BMC model used the following main data source for estimating model parameters:

- **Data collected for a national survey as part of the FAME project** (Samimi A. M., 2010). Estimates the distribution channel model transferred from the earlier CMAP model.
- **Commercial vehicle surveys collected in Texas**. Estimates shipment sizes and several of the components of the FTTM, which were transferred from the earlier CMAP model described above.
- **Research conducted by de Jong and Ben-Akiva** (de Jong, 2007). Adapts research to use in the mode and intermediate transfer model to predict the mode and path of long-haul movements of freight based on a comprehensive accounting of transport and logistics costs.
- **Ohio General Establishment Survey (Ohio DOT)**. Estimates several of the components of the CVTM and FTTM using establishment and truck diary survey.

Data Used for Model Calibration and Validation

The SHA/BMC model calibration and validation process relied on the following sources:

- Shipment-size distributions from the 2012 CFS.

- Proportions of shipments using direct or complex distribution channels based on the FAME survey.
- Mode choices by commodity and trip type segment (e.g., internal to internal, internal to external) from FAF4.
- Payloads and empty truck proportions from the 2002 VIUS.
- Distributions from the Ohio General Establishment Survey.
- ATRI truck GPS sample (distributions and O-D data derived by expansion using counts).
- Classified truck counts.

Data Desired, but not Found

Some of the desired—but unobtainable—data for use in the model included the following:

- Local data on shipping and truck travel behavior (e.g., collected using a regional establishment survey).
- Truck GPS data focused on light and medium commercial vehicles.
- Detailed data on commodities handled at individual distribution centers, warehouses, and intermodal facilities.

Detailed information about the model and the freight datasets is not yet available online.

PORTLAND METRO

Methodology

Metro received a SHRP2 C20 grant and is currently developing a new behavior-based freight and commercial vehicle modeling system. The current model development effort will produce three major components:

- **NSCM**. Connects the Portland region with the rest of the nation and includes global freight flows based on FAF data.
- **Tour-Based Freight Truck Model**. Encompasses freight delivery and pick-up movements, which converts shipments generated by the supply chain model into local truck trips.
- **Tour-Based Nonfreight Commercial Service Model**. Generates trips based on local land uses for both commercial and residential customers.

Supply Chain Modeling Needs

The new freight model will replace Metro’s current trip-based truck model that utilizes fixed commodity flows with a joint supply chain freight model and truck-touring model designed to reflect decisions made by shippers, receivers, truck operators, terminal managers, and others. The model simulates movement of individual shipments throughout the supply chain, including both direct shipments, and those that traverse transshipment facilities. The model simulates movements of all freight shipments over one year and then simulates a representative sample of shipments on an average weekday in the truck-touring model.

The objectives of the model and the project are as follows:

- Develop tools to enable a more comprehensive analysis of infrastructure needs and policy choices pertaining to goods movement.
- Develop more detailed network assignments by truck type to support regional environmental analysis, and local traffic operations and engineering analysis.
- Develop freight forecasts that are responsive to changes in economic forecasts, changing growth rates among industrial sectors, and changing rates of economic exchange and commodity flows between sectors.
- Replace trip-based truck model with advanced tour-based model.

These objectives are identified by key participants in the project including Metro, Oregon Department of Transportation, the Ports of Portland and Vancouver, the Portland Freight Committee and several local agencies (e.g., City of Portland, Southwest Regional Transportation Commission, and Clackamas County).

In applying for the grant to develop the model, Metro recognized the need for coordinated freight planning and freight's role as an economic engine for the region. This recognition facilitated the collection of freight data and the development of a new freight model. The freight model is being developed using the framework developed for FHWA and previously implemented as a demonstration project for CMAP. The model specification is being customized for the Portland metropolitan region and model parameters are being estimated or calibrated using data collected in a locally funded survey and passive data collection effort. The model uses simulated commodity flows between industrial sectors to estimate external flows into and out of the region for local producer and consumer entities, consistent with State and regional economic forecasts.

Model Structure, Component Interactions, and Segmentation

The Metro freight model is based on a combined supply chain and tour-based framework developed with FHWA research funding and implemented in Chicago and Florida with RSG's rFreight™ software. This framework comprises several steps that simulate the transport of freight between each supplier and buyer business in the United States. Figure 31 shows the supply chain processes and identifies major input and output data.

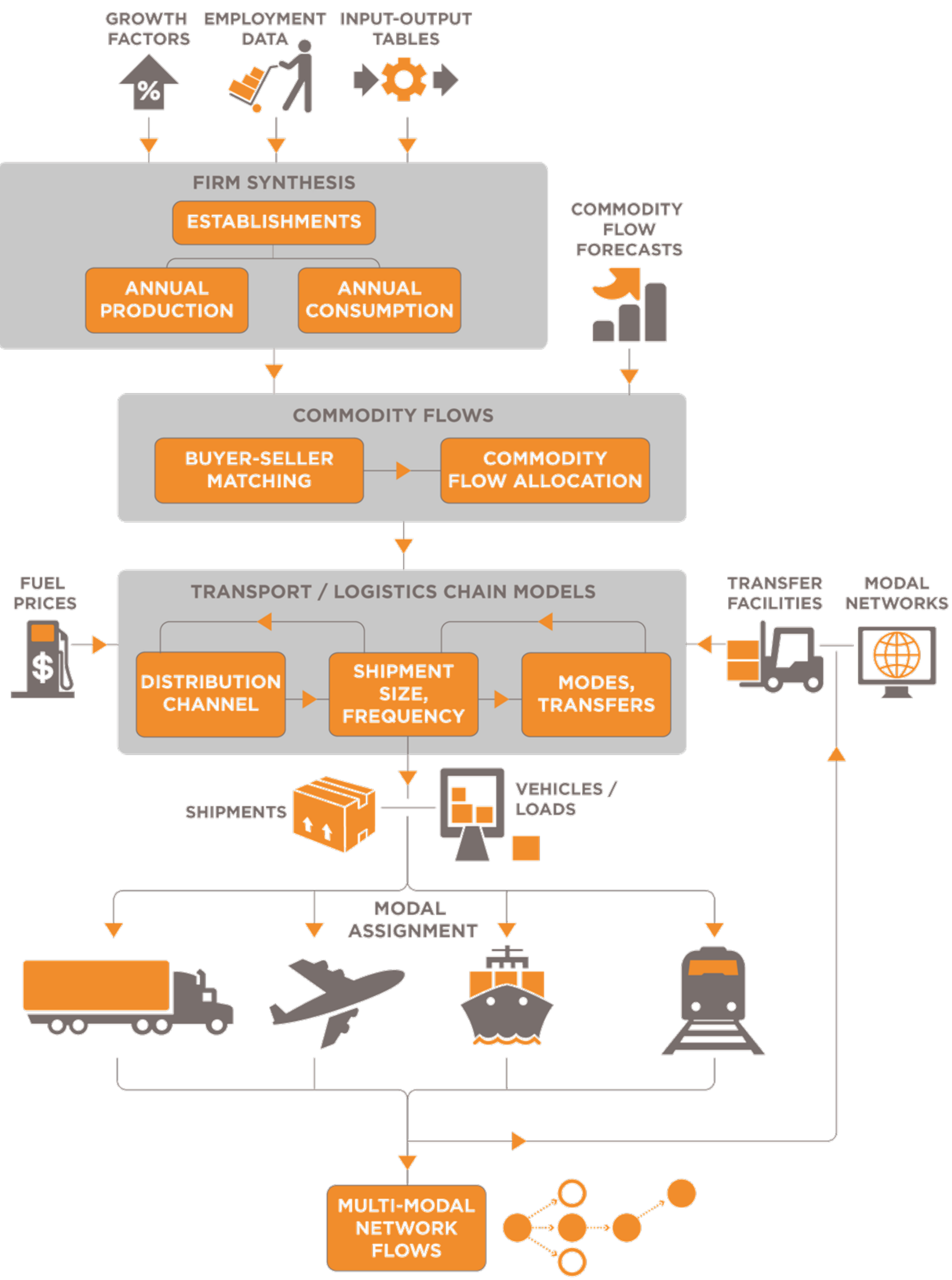

Figure 31. Metro Supply Chain Model Structure.
Source: (DKS, RSG, and Synergy Associates, 2017)

The modeling system sequence 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:

1. **Firm Synthesis**. Synthesizes all establishments in the United States and a sample of international establishments.

2. **Supplier Firm Selection**. Selects supplier establishments for each buyer establishment, by type.

3. **Goods Demand**. Forecasts the annual demand in tonnage for shipments of each commodity type between each establishment in the United States.

4. **Firm Allocation**. Allocates establishments in each county to TAZs within the Portland region.

5. **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).

6. **Shipment Size and Frequency**. Estimates discrete shipments delivered from the supplier to the buyer.

7. **Modes and Transfers**. Predicts four primary modes (road, rail, air, and waterway) and transfer locations for shipments with complex supply chains.

The supply chain model integrates with a regional truck-touring model, which is a sequence of models that takes shipments from their final transfer point to their final delivery point. The integrated modeling system connects the NSCMs with the regional truck-touring models. The final transfer point is the last point at which the shipment is handled before delivery (i.e., a warehouse, distribution center, or consolidation center for shipments with a more complex supply chain or the supplier for a direct shipment). It performs the same function in reverse for shipments at the pick-up end, where shipments are taken from the supplier to distances as far as the first transfer point. For shipments that include transfers, the tour-based truck model accounts for the arrangement of delivery and pick-up activity of shipments into truck tours.

The Metro model also includes a separate CVTM to simulate the remaining nonfreight truck movements in the model region that are not captured by the FTTM. The two truck-touring models have been transferred from the new SHA/BMC freight model described in this synthesis and have been either estimated or calibrated using the local data collected during the Portland model project.

The Metro freight model will be integrated with the passenger travel model and be part of the Metro travel demand modeling system. While the NSCM is not sensitive to local congested travel times within the Portland region—it is run using travel times and costs skimmed from a separate multimodal network—the two truck-touring models will be included within the Metro's travel demand model's feedback loops and use congested travel time skims as inputs. This means that the truck-touring patterns are sensitive to local congestion.

Market Segmentation (Industry, Commodity, Mode, Vehicle Type, Temporal, Activity Type)

The Metro freight model represents two major market segments in terms of demand for truck travel: freight movement and nonfreight commercial vehicle movement to provide services. The freight portion of the model—comprising firm synthesis, supply chain model, and FTTM—

contains several different types of market segmentation depending on the unit of analysis of each model component.

The firm synthesis model characterizes business establishments by location (TAZ), establishment size (eight employment categories ranging from 1–19 employees to over 5,000 employees) and industry (six-digit Census Bureau NAICS categories) and is controlled at the TAZ level within the Metro region using regional employment forecast data. This is grouped into 14 employment categories that are aggregations of NAICS categories. The commodity production and consumption by business establishment uses the BEA's six-digit NAICS categories, which is slightly aggregated in comparison to the U.S. Census Bureau's NAICS categories used for the industrial classification of the business establishments.

The supply chain model works with FAF commodity flow data and uses the 43 SCTG categories for segmentation of shipment commodity. The distribution channel of the shipment flow through the supply chain is segmented into direct shipments using one, two, or three transfers at distribution centers or intermodal transshipment locations. The supply chain model allocates shipments into size categories using a two-stage process, ultimately calibrating the distribution to the nine shipment-size categories, ranging from less than 50 pounds to more than 100,000 pounds used by the CFS. The shipments are allocated to one of four main modes (truck, rail, water, or air), with the intermodal paths being some combination of those modes (e.g., truck-rail-truck).

The truck-touring model uses light, medium, and heavy trucks (FHWA classes 2–3, 4–7, and 8–13, respectively) for vehicle-type categories. The output trip roster from the truck-touring model has trip start and end times defined by minute of the day. These can be aggregated into time period trip tables for static assignment. The stops that trucks make in the region are segmented into a series of different activity types. Scheduled stop activities (i.e., those where the truck is conducting its primary business) include delivery of a shipment, pick-up of a shipment, service activity, and meeting (with the latter two only relevant for nonfreight commercial vehicles). The model also adds intermediate stops for meals/breaks, vehicle service/refueling, and other purposes.

Modeled Performance Measures

The outputs from the Metro freight model include databases of business establishments, shipments by mode, and truck trips. The model aggregates truck trips into zone-to-zone trips tables and assigns these to the regional highway network to produce medium and heavy truck class volumes sorted by link. The following performance measures can be derived from the model outputs:

- Annual tonnage shipped by mode to, from, and within the Metro region by SCTG commodity. These results are available at the TAZ level.
- Mode shares of shipments by commodity and origin/destination, including imports and exports.
- Truck origin/destination patterns sorted by truck type, activity, and time of day.

- Truck volumes by truck type, time period, and link on the Metro highway network, which can be used to derive measures such as VMT and VHT aggregated spatially by area type, functional class, and facility.
- During scenario testing model users can select commodities or groups of commodities to trace through the model, including assigning to the highway network as a separate class.

Approach to Forecasting

The Metro freight model is being integrated into Metro's regional travel demand model. For forecasting future scenarios, the firm synthesis model adjusts to match the input employment data at the TAZ level. The supply chain model's main future-year and alternative scenario inputs are commodity flow data and network inputs. By default, FAF forecasts are included as commodity flow data inputs, but the model user can adjust these to evaluate scenarios with alternative future commodity flows. The network inputs include forecasted changes in daily travel times and distances due to network changes (to highway, rail networks, and waterways) and to intermodal/transfer locations (such as rail yards, ports, airports, and truck terminals/distribution centers). The truck-touring models use the more detailed time-period-specific skims because the truck-touring models are sensitive to congested travel times by time period. Thus, forecasting in these models requires future-year scenario networks for the Metro region and forecasted passenger trips to support joint assignment of passenger trips and truck trips.

Types of Applications and Procedures

The Metro freight model is multimodal and can evaluate the effect of infrastructure projects on system performance:

- **Highway Capacity Projects**. Adding general purpose lanes.
- **Managed Lane Projects**. Adding truck-only lanes or managed lanes prohibiting trucks.
- **Rail Capacity Projects**. Adding service or new terminals/routes and improving access/egress to rail terminals.
- **Port Capacity Projects**. Adding terminals and improving access/egress to ports.
- **Transfer Facility Projects**. Adding intermodal terminals or distribution centers and improving access/egress to terminals or centers.

The Metro freight model can support the following types of transportation planning projects:

- Regional transportation plans with a freight component.
- Tolls, user fees, or pricing studies, such as traffic and revenue and congestion pricing studies.
- Corridor studies and alternative analysis.
- Land-use and environmental impact studies.
- Congestion management studies.

- Accessibility to manufacturing and industrial centers.
- Operational studies, effect on speeds, and travel times.

The Metro freight model can also help evaluate the effects of private sector decisions, such as just-in-time delivery, night deliveries, and adding or moving warehouse and distribution centers.

Data

Geographic Scope

The Metro supply chain model has a global geographic scope. At its broadest, it represents import and export movements to and from international FAF zones. For the Metro model, given the proximity to Canada, the single Canadian FAF zone has been disaggregated into multiple zones based on groupings of provinces. Domestic movements are represented to and from the rest of the United States, and the model design includes simplified transportation networks that cover the entire continental United States. The model uses the FAF TAZ system and includes additional spatial detailed in Oregon and Idaho. The freight model uses the same TAZs as the current regional travel demand model within the four-county Metro region. Figure 32 shows the North American extent of the model's zone system, while Figure 33 highlights Oregon and Idaho. The regional freight and CVTMs cover the Metro modeling region. Figure 34 shows the Metro modeling region and the TAZ boundaries within the region.

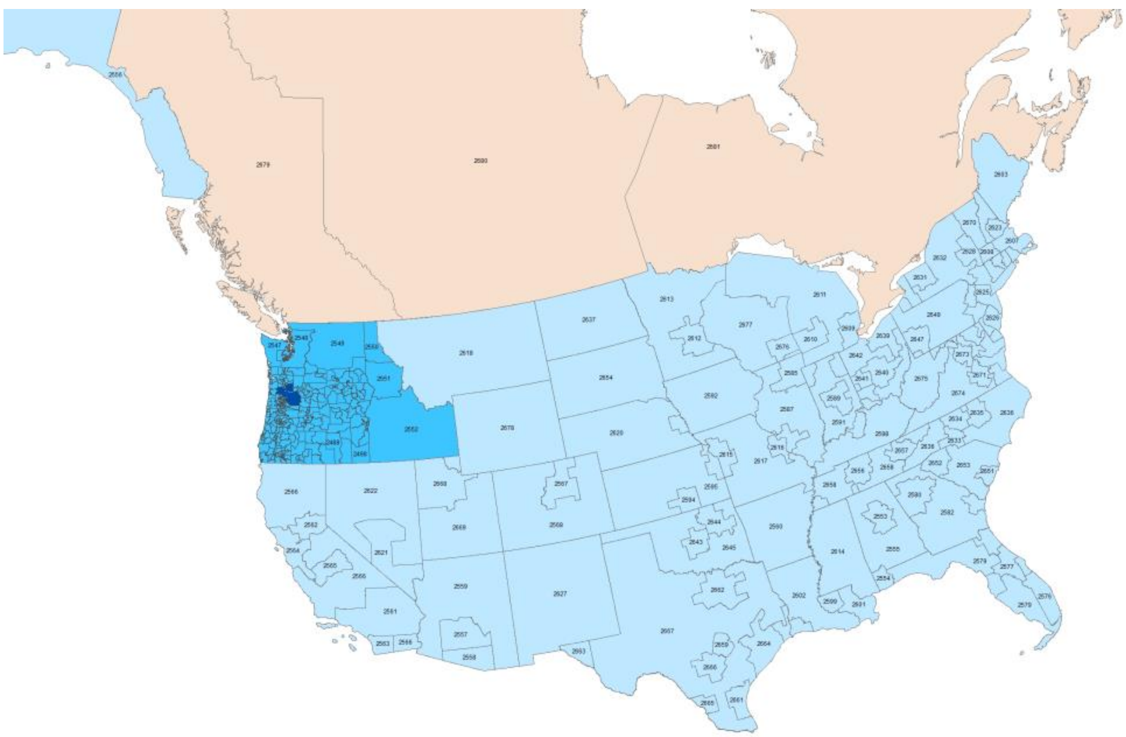

Figure 32. Metro Model Zone System, North American Extent.
Source: (DKS, RSG, and Synergy Associates, 2017)

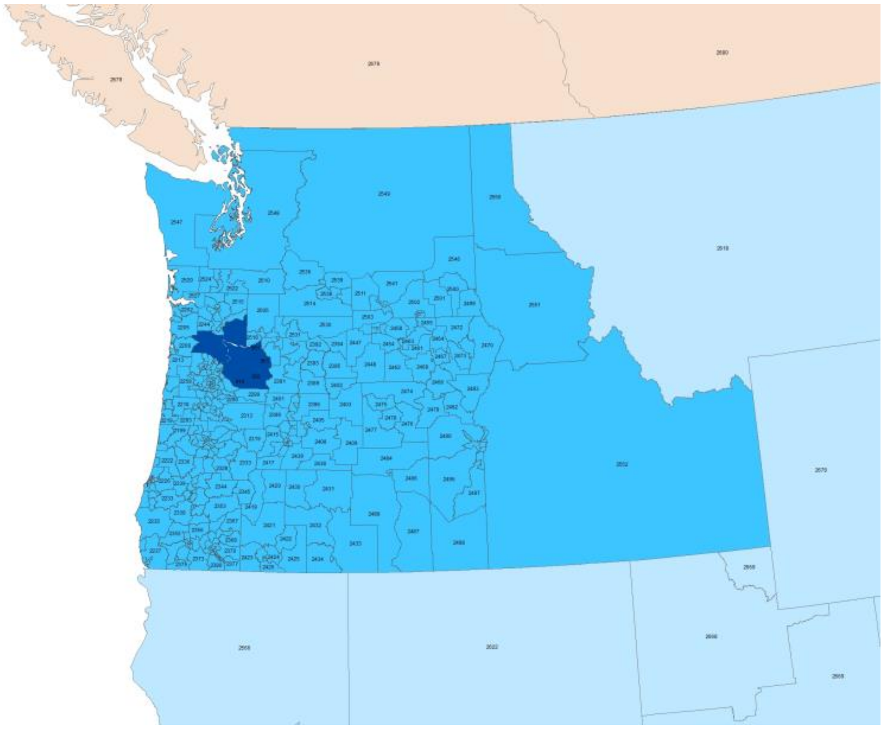

Figure 33. Metro Model Zone System, Oregon and Surrounding States.
Source: (DKS, RSG, and Synergy Associates, 2017)

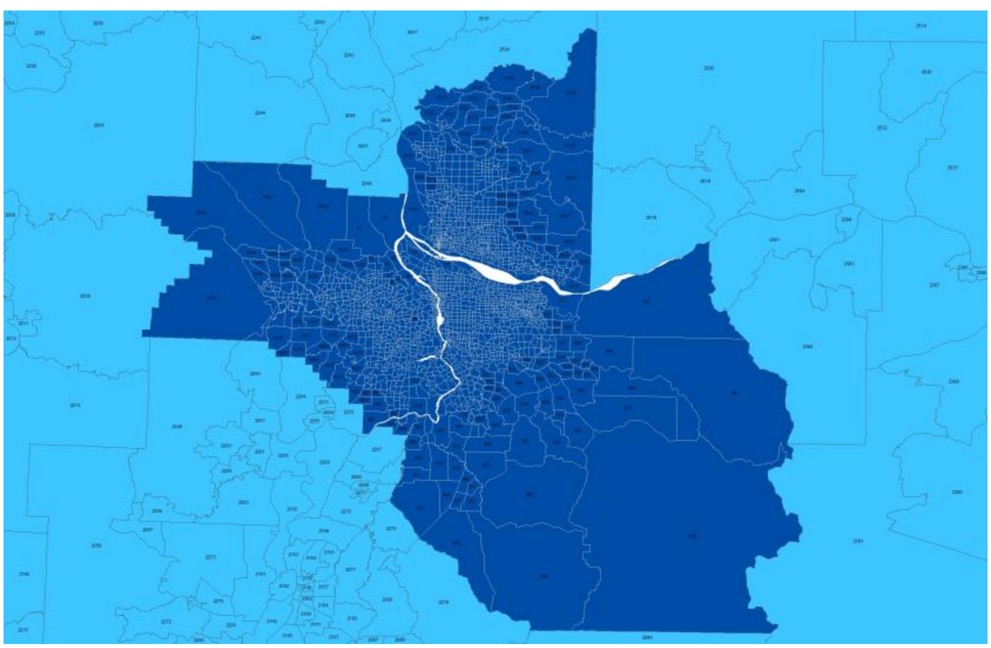

Figure 34. Metro Model Zone System, Metro Model Region.
Source: (DKS, RSG, and Synergy Associates, 2017)

Data Inputs

Metro has collected the following data to support model updates, calibration, and validation of their current truck model:

- FAF commodity flow data, refined by the Port of Portland, through a contractor.
- Gateway truck intercept survey (trucks coming from/to).
- Intercept study of transshipments, which led to a set of rules used for transshipments that were incorporated into their model.
- Ongoing count program, covering trucks though classification counts.

Metro collected data on shipping and truck travel behavior in the region for the development of the new Metro freight model. Metro used an establishment survey that collected both establishment-level data and truck driver diary data. The establishment survey employed both a traditional online survey and a smartphone app. Metro augmented the survey data by acquiring additional GPS truck movement data from INRIX, EROAD, and two businesses with truck fleets in the Portland region.

The Metro freight model uses the following main data sources as input:

- **Zone Systems**. Uses metro freight model, which combines nationwide FAF zones with TAZs in Oregon, Washington, and Idaho, and more detailed TAZs in the Metro region.
- **Economic Data**. Includes IO Make and Use tables and industry to commodity correspondences.
- **Employment Data**. Uses CBP data; Metro employment data by TAZ; LEHD data by Census block for allocation from counties to smaller geographical units.
- **Agricultural Census Data**. Uses agricultural census data to improve the identification of farms and other agricultural business establishments.
- **Commodity Flow Data**. Uses FAF4 Data for imports and exports to and from Canada were disaggregated into three Canadian zones.
- **Networks**. Uses the FAF highway network and Metro’s regional travel demand model network for highway skims, with the Metro regional travel demand model used for assignment. Bases the model’s nonfreight networks for rail, waterways, and the locations of ports, airports, and intermodal facilities on the NTAD.
- **Distribution Centers and Warehouses**. Includes a database of the locations of distribution centers and warehouses developed by Metro.

Data Used for Estimating Model Parameters

The Metro freight model used the following main data sources for estimating model parameters:

- **Data collected for a national survey as part of the FAME project** (Samimi A. M., 2010). Uses these data to estimate the distribution channel model transferred from the earlier CMAP model.

- **Commercial vehicle surveys collected in Texas**. Uses these data to estimate the shipment sizes model and several of the components of the FTTM, which were transferred from the earlier CMAP model.
- **Research conducted by de Jong and Ben-Akiva** (de Jong, 2007). Adapts these data to use in the mode and intermediate transfer model to predict the mode and path of long-haul movements of freight based on a comprehensive accounting of transport and logistics costs.
- **Ohio General Establishment Survey (Ohio DOT)**. Uses data from establishment survey to estimate several of the components of the CVTM and FTTM.
- **Portland commercial driver diary survey**. Uses data from the truck diary survey conducted as part of the project to estimate several of the components of the CVTM and FTTM.
- **EROAD dataset for the Portland, Oregon, area**. Uses these data to estimate several of the components of the CVTM and FTTM. EROAD is a company that provides onboard vehicle monitoring systems to trucking companies.
- **INRIX dataset for the Portland, Oregon, area**. Uses these data to estimate several of the components of the CVTM and FTTM. INRIX is a well-known provider of mobility analytical services and smartphone navigation apps.
- **Business-specific truck diary datasets**. Uses these data to estimate several of the components of the CVTM and FTTM. Two businesses in Portland provided fleet monitoring data for their truck fleets, including similar information to truck diary survey data.

Data Used for Model Calibration and Validation

The calibration and validation of the Metro freight model relied on the following sources:

- Shipment-size distributions from the 2012 CFS.
- Proportions of shipments using direct or complex distribution channels based on the FAME survey.
- Mode choices by commodity and trip type segment (e.g., internal to internal, internal to external) from FAF4.
- Payloads and empty truck proportions from the 2002 VIUS.
- Distributions from the Ohio General Establishment Survey.
- GPS data from combination of truck diary survey, INRIX, EROAD, and business fleets (distributions and O-D data derived by expansion using counts).
- Classified truck counts.

Data Desired, but not Found

Some of the desired—but unobtainable—data for use in the model included the following:

- Detailed data on commodities handled at specific distribution centers, warehouses, and intermodal facilities.
- Data on nonhighway access to specific businesses (e.g., those having rail spurs allowing direct rail deliveries).
- Detailed information about the model and the freight datasets is not yet available online.

SUMMARY

This summary of agency experiences focused on advanced freight forecasting models with elements of supply chain, including firm synthesis, procurement market models, transportation and logistics supply chain models, or truck movement models. This chapter reviewed and summarized seven in-use behavioral supply chain freight models. Table 9 summarizes the models reviewed.

Table 9. Review of Freight Forecasting Models.

Model	Region	Context	Modes Considered (assigned)	Firm Synthesis (model type)	Buyer-Supplier Matching (model type)	Supply Chain Allocation (model type)	Mode and Shipment Size (model type)	Tour-based Truck (model type)	Platform
Chicago	Chicago Metro	Freight	Truck, rail, air, water	Establishment enumeration	Game theory	MNL model	Ben-Akiva and de jong utility equation, MNL model	MNL models, greedy algorithm	R
Florida	State of Florida	Freight	Truck, rail, air, water (truck)	Establishment enumeration	Fuzzy logic	MNL model	Ben-Akiva and de jong utility equation, MNL model	N/A	R
Baltimore/ Maryland	Baltimore	Freight and services	Truck, rail, air, water (truck)	Establishment enumeration	Fuzzy logic	MNL model	Ben-Akiva and de jong utility equation, MNL model	MNL models, TSP algorithm, hurdle/count models	R
Portland	Portland Metro	Freight and services	Truck, rail, air, water (truck)	Establishment enumeration	Fuzzy logic	MNL model	Ben-Akiva and de jong utility equation, MNL model	MNL models, TSP algorithm, hurdle/count models	R
Phoenix	Phoenix	Freight and services	Truck, rail, air, parcel (truck)	Establishment evolution	ACE	ACE	Nested Logit	MNL models	R and Java
Oregon	State of Oregon	Integrated model (with CT module)	Truck, rail, air, water, pipeline (truck)	N/A	N/A	N/A	Monte Carlo process	TSP algorithm	R and Java
Wisconsin	State of Wisconsin	Freight and services	Truck, rail, air, water (truck and rail)	Establishment enumeration	Fuzzy logic	Ben-Akiva and de jong utility equation	Ben-Akiva and de jong utility equation	Gravity models	R

CHAPTER 5. BEHAVIORAL/SUPPLY CHAIN FREIGHT MODEL ASSESSMENT

This chapter details the findings of the state-of-the-practice model review, which aims to help agencies assess the feasibility of a behavioral/agent-based supply chain modeling approach. The review includes a list of considerations for planning the model development. For the purposes of this discussion, a study area could encompass a region, megaregion, or an entire State.

FREIGHT MODEL DESIGN

The following sections summarize the experience of the agencies interviewed for this synthesis. These sections discuss commonalities that led the agencies toward behavioral/agent-based supply chain models as the preferred solution to support their freight modeling and freight planning needs.

Current Freight Model Structures

An agency's decision to transition to a more advanced freight model structure must weigh the investment cost of transitioning against the importance of answering detailed policy and planning questions. The previous models of the agencies examined as part of this synthesis were relatively limited trip-based models that analyzed—at most—grouped commodities and often represented only trucks. In these cases, the models provided little of the market coverage and policy sensitivity required to answer complex policy questions.

Most supply chain model components reviewed as part of this synthesis were based on multinomial or nested logit choice model formulations. The first step of these supply chain models is an enumeration of establishments, typically called firm synthesis, based on iterative proportional fitting methods. The buyer-supplier matching model component is based on different methods, with the most advanced being a game theory application. Buyers consider several transportation, logistics, risk, capacity, and productivity factors for sellers when selecting a seller. Some buyer-supplier matching models use fuzzy logic or agent-based computational economics (ACE). In the MAG model, the supply chain allocation model used the ACE method. Tour-based truck models primarily use the multinomial logit choice approach, except in the Wisconsin and Oregon models where TSP algorithm and gravity models were used. In several cases, the stop-sequencing element of the truck-touring models used a different approach, such as the greedy algorithm and the hurdle/count model.

More advanced passenger models are following similar development paths, where the more complex policy analyses being undertaken now have led to the transition to activity-based (AB) models. One factor in deciding to transition to a more advanced freight model is the benefit of adding commensurate detail to the modeling of freight vehicle movements once passenger vehicles are represented in a more detailed way. An issue that is more closely related to the truck-touring models than to supply chain models is the ability to integrate the outputs directly with dynamic assignment models.

Desired Geographic and Temporal Coverage

The most expansive supply chain freight models include a large geographic and temporal scale. This expansive design is meant to accurately capture freight movement, which is part of a global system that operates continuously. For example, the Chicago Metropolitan Agency for Planning (CMAP) model examined as part of this synthesis simulates the entire U.S. economy and imports and exports, which is appropriate given Chicago's importance to the nation's freight movement system. Many of the supply chain models aim to track the shipment supply chains that affect freight movements in their study area to international origins and destinations for imports and exports, and their domestic origins and destinations for domestic shipments. The extent to which through-freight movements are considered is also important for study areas that contain water ports, as this can broaden the model's geographical detail. For example, the FreightSIM model of Florida also includes significant detail in the adjoining States of Georgia and Alabama.

Decisions on temporal coverage are driven somewhat by the datasets used to forecast freight movements, many of which operate on an annual timeframe. The transition to daily traffic for assignment purposes, and more detailed time-period-specific traffic volumes, is often made later in the model systems (e.g., in a connected truck-touring model).

Although none of the models described in this synthesis had implemented seasonal variation in commodity flows yet, this is a promising and ongoing area of research for academics working on the development of freight model techniques. The disaggregate nature of supply chain models facilitates simulating seasonal variation in the production and consumption of commodities. Unlike passenger travel that has more predictable activity patterns by time of day, freight movements are more heavily influenced by seasonal variations that vary by commodity.

Desired Market Coverage

Market coverage requirements are an important consideration when identifying a need for a supply chain model. The models reviewed as part of this synthesis generally support extensive segmentation and the ability to track segments through the model system. The disaggregate nature of the models supports this with characteristics of individual businesses and shipments that support the high number of combinations of industrial classifications and commodities. The issues for different typical model steps included in the supply chain models and connected truck models are described in the following subsections.

Firm Synthesis

- Characterizes business establishments by location (e.g., traffic analysis zone [TAZ], county, State), establishment size (e.g., employment categories), industry (e.g., six-digit Census Bureau NAICS categories).
- Addresses market coverage issues inherent in some of the typical business establishment data, particularly relating to agricultural businesses (i.e., farms) and home-based businesses.

- Scales the number and size of establishments in a firm synthesis model at the TAZ level. These often use regional employment forecast data, since future business establishment data are typically not developed by transportation planning agencies.
- Bases commodity production and consumption by business establishment on the U.S. Bureau of Economic Analysis's (BEA's) Input-Output (IO) data. These data use the BEA's six-digit NAICS categories and provide coverage across the whole economy.

Supply Chains

- Develops the shipment movements between pairs of firms. The disaggregate nature of the production and consumption outputs from the firm synthesis models supports detailed buyer and supplier matching and allocation of commodity flows. Many of the models use the full range of 43 SCTG categories for shipment commodities.
- Supports the representation of the complete distribution of shipment sizes (e.g., using the nine shipment-size categories from the Commodity Flow Survey (CFS), ranging from less than 50 pounds to more than 100,000 pounds), via the conversion from annual commodity flows to individual shipments.
- Supports analysis of the freight mode choice by being fully multimodal. Many of the models use four main modes (truck, rail, water, or air), with the intermodal paths being represented as some combination of those modes (e.g., truck-rail-truck). Some of the models also include movements, by pipeline.

Truck Types and Truck Activities

- Integrates (to some extent) with regional truck models. Two major market segments are typically used in terms of demand for truck travel: freight movement and nonfreight commercial vehicle movement to provide services. Usually, only the freight truck models are connected to the supply chain model.
- Predicts truck movements for different truck types, such as light, medium, and heavy trucks (Federal Highway Administration [FHWA] class 3-5, 6–7, and 8–13, respectively) for vehicle-type categories. The output trip rosters from truck-touring models usually have detailed trip start and end times (e.g., defined by minute of the day) that can be aggregated into time period trip tables for static assignment.
- Accounts for different activity types via the stops that trucks make across freight and commercial vehicle segments. Scheduled stop activities (i.e., those where the truck is conducting its primary business) include delivery of a shipment, pick-up of a shipment, and service activities. The models often also add intermediate stops for meals/breaks, vehicle service/refueling, and other purposes. This range of activities provides responsiveness to land-use changes and can support policy tests such as delivery windows and other policies that relate to the truck activity occurring at a stop.

The specific coverage and segmentation available to a model step is related to the unit of analysis of the model and the range of characteristics that can be used to describe the decision-makers represented in the model step.

Forecasting Methods

The available case studies approach to forecasting integrates truck trips with passenger car trips to conduct highway assignments in the base and future-year scenarios. This allows congestion to influence cars and trucks equitably and for planners to evaluate the benefits of future strategies to alleviating congestion for both cars and trucks. Truck trip tables by type and time period are included in a multiclass assignment.

None of the available case studies includes the assignment of rail, water, air, or pipeline freight trip tables. These are long-distance modes and would require operational models to evaluate capacity constraints, which are quite time consuming and data intensive to develop. Since the supply constraints are not as significant for non-highway modes, these operational models are often not warranted at a regional or statewide scale.

Future-year scenarios require travel times and costs by mode, future-year employment data, and future-year facilities' data (e.g., distribution centers, intermodal terminals, ports). All of the models forecast specific future years for planning purposes, but the Oregon model steps through time in one-year intervals up to the desired forecast year. Most agencies rely on future-year commodity flow data as an input, but the Chicago and Oregon freight models have the capability to generate future-year commodity flows.

Staff Resources for Data Processing and Model Maintenance

Transportation agencies will derive the greatest benefit from their behavioral supply chain freight models by allocating sufficient staff for operations and maintenance of various input, estimation, calibration, and validation datasets required to apply the modeling system. Dedicated staff resources provide an opportunity for staff to become familiar with the data processing required for updating input data sources and interpreting the results of the freight modeling system. Ideally, this would be one or two full-time staff, but many transportation agencies will begin with 0.5 full-time equivalent staff resources. Many transportation agencies have transportation planners who focus on freight planning and become familiar with freight datasets, while travel forecasting staff study and understand the supply chain modeling components. Working together, the planners and modelers bring different expertise to the larger question of understanding freight movements. Behavioral supply chain freight models are complex and require training and experience to maintain and apply. Given the relative newness of these models, training should be obtained from model developers since there are no standardized courses available in these methods.

Consideration of Phased Approaches to Development

Phasing the freight model development process permits funding the work across fiscal years. Figure 35 illustrates two different approaches to phasing the freight model (if a commercial vehicle survey of establishments is conducted). In the second example, model implementation is accomplished by transferring a model during model implementation and then revising parameters based on the model estimation. In both examples, the commercial vehicle surveys and model estimation can be dropped entirely using the transferred model approach.

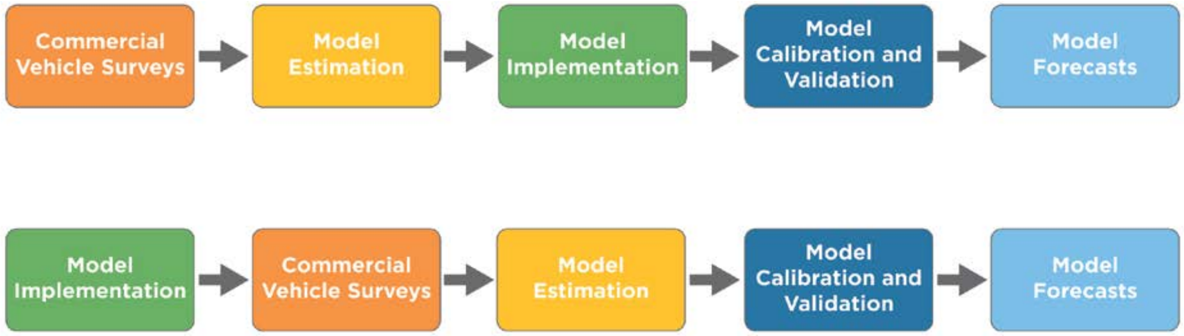

Figure 35. Two Examples of Phasing with a Commercial Vehicle Survey.
Source: (RSG, 2017)

Another approach to phasing involves developing model system components in different phases (Figure 36). The most obvious approach is to develop the model system components in the sequence that they are processed. The alternative approach is to develop the local goods movement models first by using a fixed demand for interregional corridors and global gateways. Decisions around this phasing typically involve deciding which model system component addresses the most important regional planning needs.

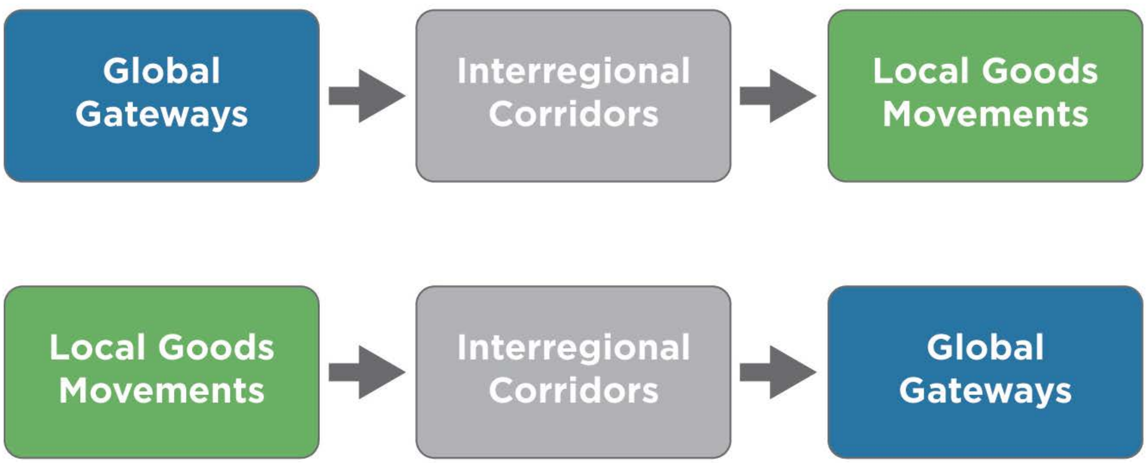

Figure 36. Two Examples of Phasing, by Model System Component.
Source: (RSG, 2017)

COLLABORATION OPPORTUNITIES (PUBLIC SECTOR PARTNERSHIPS)

The ability to unite the resources sufficient for a successful freight modeling program can be greatly aided through cooperative partnerships between an agency and other organizations with shared interests. These resources may include sharing data, software, and computing resources, as well as joint funding of model development or maintenance activities. An obvious place to start would be regional stakeholders, who might benefit directly from the freight modeling program. Less obvious—but nonetheless valuable—partnerships might be with agencies outside of the agency's region, which also develop and maintain freight modeling programs.

Development of advanced freight demand models is increasingly executed in phases, which often begin with the transfer of a model structure and parameters from another region. This is one feasible path to take in developing a new freight modeling system. In addition, it is also increasingly common for metropolitan planning organizations (MPOs) to co-fund large data collection efforts. Establishment surveys that collect either origin-destination data or full driver diary data can be resource-intensive and partnerships with adjacent MPOs within the region could provide an excellent opportunity for shared data collection for freight. An example of an active megaregional modeling region is in Arizona where Maricopa Association of Governments (MAG) (Phoenix) and the Pima Association of Governments (PAG) (Tucson) have shared data and modeling resources for passenger, freight, and land-use modeling systems.

Cost for the development of application software for a freight modeling system can be minimized by borrowing open-source application programs that have been developed for other regions and customizing it only as needed to suit the specifications of the region. For example, the rFreight package developed by RSG in the open-source language R, has been implemented to suit the needs of five different agencies, with the main modifications being data inputs and parameter estimates. This also provides a user community and the opportunity to contribute and receive updates as rFreight is refined and enhanced.

CHAPTER 6. FREIGHT PERFORMANCE MEASURES

FREIGHT MODEL STATISTICS

Freight-related performance measures are often segmented by commodity group and mode. Commodity flows are typically summarized by weight (tonnage) and value (dollars) and most often reported annually. Shares by mode or market is another means to evaluate commodity flows across different scenarios or geographies using a normalized measure. The following performance measures are used to quantify commodity flows:

- Annual tonnage shipped by commodity group and mode to, from, and through the study area.
- Cost per ton of freight shipped by commodity group and mode.
- Annual import and export tonnage, by port.
- Mode shares of tonnage by commodity group, including imports and exports by district/county.
- Market share of international or domestic trade.

Travel time is an important attribute for any freight model; this attribute is also an important means of measuring the performance of the system. Since this is both an input to the system and a measure of performance, it is important to validate travel times against observed data before relying on the performance measures. Typically, these travel times represent an average daily travel time, but these may also be reported by time of day. Travel times for freight can be reported in several ways:

- Origin-destination (O-D) travel times, by commodity group and mode.
- Daily truck travel times for select O-D pairs.
- Truck VHT.

Advanced freight models that include behavioral or agent-based supply chain methods represent trips as segments of a long-distance supply chain. Such models may also represent the pick-up and delivery system to deliver goods for the last portion of the supply chain. Once the supply chain has been established, each segment is identified as a trip with a specific origin and destination. These trips can be reported by commodity group, mode, and aggregation of TAZs (i.e., districts or counties) and can be for annual or daily time periods. Truck trips are segmented further by truck type, time of day, and user class—typically for daily time periods. Pick-up and delivery systems for truck travel within a study area can also be reported as stops per tour, tour length, stop duration, and other tour statistics, also typically for daily time periods. Freight trips can be reported in several ways:

- Trips by commodity group and mode and district/county.
- Trips by truck type, time of day, and user class.
- Truck tour statistics for trips within study area.

An important performance measure for transportation planners is average daily truck volumes, reported by road segment, screenline, or facility type. Truck volumes can also be summarized by geography (i.e., district or area type). Truck volumes are typically not segmented by commodity group, but if an agency was interested in this performance metric, then it could be developed by assigning truck trips for a single commodity group or by assigning several commodity groups using a multiclass assignment technique. The following represents several performance measures for truck volumes:

- Daily truck volumes by truck type, time of day, and road segment.
- Daily truck volumes by district, area type, facility type, and screenline.
- Truck VMT.
- Truck volumes for a selected commodity group.

In addition to the performance measures considered in modeling, there are also performance measures related to operation of highways, including: travel time index, planning time index, buffer index, average hours of delay for freight vehicles, and safety measures.

All of the agencies included in the synthesis (except WisDOT) employed assignment of rail, air, water, or pipeline flows. Since most commodities travel by truck, and since the operational models for rail, air, water, and pipeline are complex—and typically only developed for site-specific applications (rather than regional, megaregional, or statewide study areas)—many agencies do not assign rail, air, water, or pipeline flows. As a result, this report does not include performance measures associated with these modal volumes.

Table 10 summarizes the performance measures sorted by type.

Table 10. Summary of Performance Measures, by Type.

Performance Measure	Commodity Group	Mode	Imports/ Exports	Domestic	External[1]	Internal[2]	Truck Type	Annual	Time of Day
Commodity Flows	✓	✓	✓	✓	✓			✓	
Travel Time	✓	✓		✓	✓	✓			✓
Trips	✓	✓	✓	✓	✓	✓	✓	✓	✓
Truck Volumes						✓	✓	✓	✓

1. External refers to the segment of the freight movements that have some portion of the movement outside the study area but travel through, into, or out of the study area.

2. Internal refers to the segment of the freight movements that are entirely within a study area.

PUBLIC SECTOR PERFORMANCE METRICS

The public sector primarily utilizes performance measures to quantitatively assess progress toward agency goals. Though there are several performance measures, most typically fall into the following categories:[1]

1. Transportation System Performance
    a. Efficiency
    b. Reliability
2. Safety
3. Environmental Sustainability
4. Economic Indices
5. System Preservation

Important components of performance management are longitudinal measurements and trends analysis. An agency may determine that additional investment or a policy change is required based on positive or negative changes in an individual PM over time. For example, an agency may decide to invest in highway improvements in situations where highway infrastructure is demonstrated by a PM to be either degraded or inefficient in terms of operations.

Previously, PM data relied heavily on travel models and estimates.[2] However, there has recently been a shift toward empirical data measurements. [3,4] For instance, technological advances have produced additional travel data from roadside technologies (such as loop detectors) and onboard vehicle systems (such as GPS data).[5] These types of travel data are more accurate than modeled data, but empirical data are not always available for all measures.[6]

Transportation System Performance

Generally, transportation system performance measurements focus on the time it takes vehicles to travel from one location to another, or what a vehicle's speed is at a given location. Vehicle speed at a given time and location can be measured through calculations of spot speed averages that are captured from an onboard device or from a roadside device. Average speeds and travel times across a given distance are more complex and require at least two points of reference with

[1] Katherine Turnbull. "Performance Measurement of Transportation Systems: Summary of the Fourth International Conference," 2013.
[2] Katherine F. Turnbull. "Adapting Freight Models and Traditional Freight Data Programs for Performance Measurement." Transportation Research Board, 2013.
[3] "Regional Indicators - CMAP." Accessed March 23, 2017. (enumerated web address: http://www.cmap.illinois.gov/data/regional-indicators).
4 Ibid.
[5] Ibid.
[6] Ibid.

time and location information. Measures of delay can be quantified using travel times; these measures can also indicate when, where, and for how long a location or system is performing below a target.[7] VMT information can also help determine the full effect that low-performing roads have on roadway users. Roadway deficiencies can be applied to the full population of system users using VMT, speed, and travel time, which helps calculate underperforming facilities' costs.

Disaggregation of efficiency measures by day of week, time of day, or other variables can also provide insight into the factors that influence efficiency on roadway segments.[8] An example of segmentation by time of day and the use of performance measures to evaluate efficiency is ATRI's annual Top Truck Bottlenecks list. As shown in Figure 37 below, the worst truck bottleneck in 2017 was I-285 at I-85 north in Atlanta, Georgia; a roadway segment with an average speed of 38 miles per hour (mph), a peak average speed of 26 mph, and a nonpeak average speed of 44 mph.[9] Segmenting these data by time-of-day information can help identify optimal times to route freight through these bottlenecks (Figure 37).

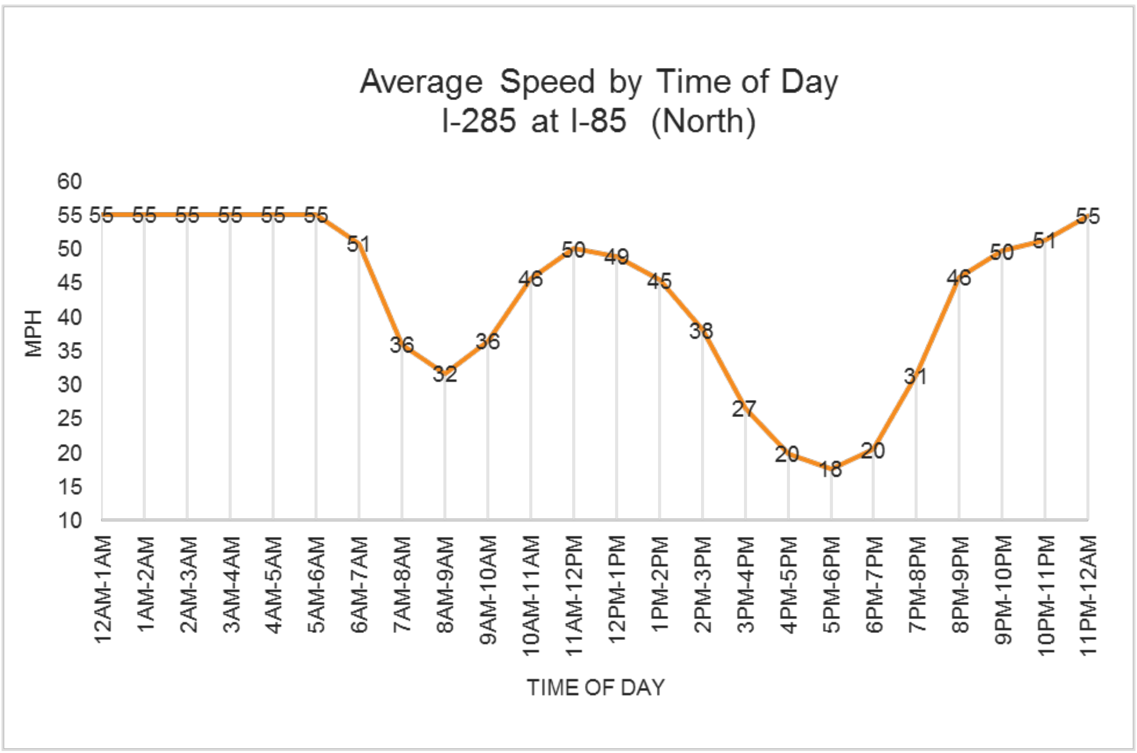

Figure 37. Example of Peak-Hour Congestion.
Source: (American Transportation Research Institute, 2017)

[7] Katherine Turnbull. "Performance Measurement of Transportation Systems: Summary of the Fourth International Conference," 2013.
[8] Katherine F. Turnbull. "Adapting Freight Models and Traditional Freight Data Programs for Performance Measurement." Transportation Research Board, 2013.
[9] "Atlanta, GA: I-285 at I-85 (North)." Accessed March 23, 2017. (enumerated web address: http://atri-online.org/research/results/congestion_mobility/2017bottleneck/001.pdf).

Reliability performance measures, which require average speed or travel time as an input, help quantify the variability and predictability of travel times.[10] Reliability performance measures include measures such as nonrecurring delay frequency, percentage of on-time arrivals, travel time indices, buffer indices, and planning time indices.[11,12] As an example, a buffer index is the *additional* time needed to ensure an individual arrives at his or her destination on time, 95% of the time. Planning time indices, on the other hand, estimate the *total* amount of time that must be set aside to arrive at a destination on time, 95% of the time.[13] The planning index differs from the buffer index by including unexpected delays and delays that are recurrent.

Safety

Safety-related measures focus on crash incidence or rates. The incidence or rate of fatalities, injuries, and property damage on roadways are common safety performance measures.[14] Segmentation of roadways to identify high-risk segments can guide where infrastructure investment will have the greatest effect. The use of roadway-specific data or information on crash causes can further inform what types of roadway improvements would have the greatest effect on safety outcomes. The relative effect of infrastructure investments can be measured through the percent change in fatality, injury, or property-damage-only crash rates.[15]

Most data used for monitoring and analyzing data comes from U.S. DOT databases such as the Motor Carrier Management Information System (MCMIS), and sub-databases generated from MCMIS. MCMIS itself is populated by State crash and safety data submissions. It is well understood that the submissions are not always complete nor standardized, thus requiring researchers and planners to [attempt to] substantiate certain data without secondary sources. Ultimately, most government entities set truck safety objectives and measures based on guidance from the Federal Motor Carrier Safety Administration, and proposed through annual Motor Carrier Safety Assistance grant applications.

Environmental Sustainability

Environmental sustainability performance measures relate to pollution levels, and the effects of pollution, from vehicle emissions. performance measures include items such as per capita carbon dioxide emissions, fuel use, air quality, premature deaths caused by emission exposure, and greenhouse gas emissions.[16]

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[10] "Travel Time Reliability: Making It There On Time, All The Time." Accessed March 23, 2017. (enumerated web address: https://ops.fhwa.dot.gov/publications/tt_reliability/TTR_Report.htm).

[11] Katherine Turnbull. "Performance Measurement of Transportation Systems: Summary of the Fourth International Conference," 2013.

[12] "Travel Time Reliability: Making It There On Time, All The Time - Brochure - FHWA Office of Operations," Accessed March 23, 2017. (enumerated web address: https://ops.fhwa.dot.gov/publications/tt_reliability/brochure/).

[13] Ibid.

[14] Katherine Turnbull. "Performance Measurement of Transportation Systems: Summary of the Fourth International Conference," 2013.

[15] Ibid.

[16] Katherine Turnbull. "Performance Measurement of Transportation Systems: Summary of the Fourth International Conference," 2013.

Measures of environmental sustainability are generally quantified using the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) model. MOVES is used for inventory development in State Implementation Plans and for regional emissions analysis for transportation conformity determinations ("regional conformity analyses") in States other than California. MOVES estimates emissions for both highway vehicles and nonroad equipment.

MOVES contains a number of modeling parameters including vehicle types, time periods, geographical areas, pollutants, vehicle operating characteristics, and road types. The model performs a series of calculations, based on vehicle operating characteristics, to estimate total emissions or emission rates per vehicle or unit of activity. Changes to these modeling parameters ("user specified parameters") can be used to evaluate the emissions impact of changes in freight performance. For example, changes in vehicle speeds ("speed distribution"), mileage ("vehicle miles traveled") and extended idling ("hoteling") are parameters than can be adjusted to account for changes in travel patterns or roadway characteristics.

Economic Indices

Performance measures related to economic conditions require a defensible method of demonstrating how transportation influences gross domestic product or gross regional product.[17] An example of an economic performance measure is new job growth resulting from infrastructure improvements. Other uses of economic indicators demonstrate the cost of efficiency losses. An example is the cost of congestion on the National Highway System (NHS) to the trucking industry—728 million hours of delays, or approximately $49.6 billion dollars in increased costs.[18]

When econometric models are used, modelers build freight transportation models for tonnage or revenue, they calculate outputs by forecasting the freight, not the modes themselves. In other words, this top down "gravity" approach looks at the split of manufacturing activity by commodity for each mode. Then, the modelers forecast the growth in that commodity, and run those economic forecasts through a freight transportation model to yield the growth by mode. While there could be mode shifts, they are relatively small historically speaking.

System Preservation

System preservation goals primarily relate to the reduction of vehicle maintenance costs and are measured through pavement ride quality and bridge quality. In the United States, the Highway Performance Monitoring System collects these data.[19] An example of a system preservation measure is U.S. pavement ride quality, which has reduced significantly in recent years. From

[17] Katherine Turnbull. "Performance Measurement of Transportation Systems: Summary of the Fourth International Conference," 2013.

[18] W. Ford Torrey. "Cost of Congestion to the Trucking Industry." American Transportation Research Institute, April 2016.

[19] "Executive Summary - 2015 Conditions and Performance - Policy | Federal Highway Administration." Accessed March 23, 2017. (enumerated web address: https://www.fhwa.dot.gov/policy/2015cpr/es.cfm#3h).

2002 to 2012, national highway road mileage that was rated as acceptable decreased from 87.4% to 80.3% on NHS roadways.[20]

System preservation is typically measured by the freight infrastructure condition and capacity. For example, the ratio of heavy or overweight trucks to total trucks is a measure that can be utilized by the models. Highway pavement and bridge conditions are other measures that are tied to freight system performance and can help with system preservation. Number of truck weigh stations on the network or percent of roadway miles with acceptable ride quality are measures that freight models utilize to inform on system preservation and performance. Total air tonnage at an airport is another system preservation performance measure that a freight model can be used for.

PRIVATE SECTOR PERFORMANCE MEASURES

The trucking industry is competitive since the barriers to entry are low. Thus, profit margins are low when compared to other industries. As a result, trucking firms must scrutinize all cost centers to increase efficiency. To better understand private sector performance measures, the project team considered internal knowledge of the trucking industry, reviewed relevant articles and reports, interviewed a trucking operations executive, and surveyed carrier managers of operations. Private sector performance measures typically fell into one of the following categories: operations, financial, or safety. The tracking of performance measures is crucial to identifying areas of improvement and tracking progress in achieving organizational goals. An example of the importance of performance measures to carrier operations is demonstrated through the practices of USA Truck, a 2,000-power unit fleet that utilizes approximately 300 performance measures.[21][22] Some performance measures are common across the private sector, while others are unique to individual carriers.[23] Additional variation in private sector performance measures is introduced by different business models or financial practices, such as per-load or per-mile compensation metrics. A carrier may incorporate additional segmentation to account for differences in business divisions.

Operations

Operations performance measures focus on managing costs and optimizing asset utilization. Cost management is critical due to the small profit margins characteristic of motor carriers. Optimizing asset utilization is equally important—carrier revenue is dependent on moving freight; therefore, stationary equipment or equipment operating unloaded are both large cost centers. Operations performance measures are sometimes best understood when considering the entire fleet, while at other times operations performance measures must be segmented to be meaningful. The following discussion highlights several examples of key trucking company performance measures:

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[20] Ibid.

[21] "Safety Measurement System - Overview (U.S. DOT# 213754)." Accessed March 24, 2017. (enumerated web address: https://ai.fmcsa.dot.gov/SMS/Carrier/213754/Overview.aspx).

[22] Wayne D. Cottrell. "Performance Metrics Used by Freight Transport Providers," September 30, 2008.

[23] Ibid.

- **Tracking empty miles.** Those miles driven where no revenue-generating freight is on board, is categorized as "extremely important" to the industry.[24] Motor carriers will track how many miles driven are revenue-earning miles versus nonrevenue miles. As a PM, empty miles may be reported as a percentage of total miles with the goal of decreasing that percentage. No publicly available data source exists for this, as each motor carrier tracks this relatively sensitive metric internally. The American Transportation Research Institute's (ATRI's) annual "Operational Costs of Trucking" report provides aggregate statistics on empty or "dead-head" miles.
- **Fuel economy.** Fuel represents one of the largest costs for trucking fleets.[25] Fleets may track average miles per gallon at a fleet or individual driver level as a PM.
- **Service**. Service-related operation performance measures include measures such as on-time pick-up percentage, on-time delivery percentage, and claims-free service percentage.[26]
- **Company asset utilization.** Equipment utilization rates and driver availability is also addressed in operations. Carriers may consider the number of drivers currently off work and trends related to available equipment when making hiring or recruiting decisions.
- **Characteristics segmented by haul or driver.** Average length of haul, freight volume, tonnage, and miles driven per day. [27,28]

Notably absent from operational performance measures are measures related to congestion and speed—the three large carrier PM areas reviewed in *Performance Metrics Used by Freight Transport Providers* did not have any performance measures for congestion or speed.[29] However, these might be performance measures of significant interest to carriers since avoiding congestion and maintaining off-peak speeds reduces costs.

Financial

Financial performance measures represent the greatest proportion of performance measures utilized by the private sector, a result of the relationship between carrier finances and economic viability.[30] Revenue-related-performance measures include revenue per loaded mile, revenue per mile, and revenue per shipment. Similarly, cost performance measures are also of significant importance to the private sector. Per-mile and per-load costs of operation are of interest to carriers. ATRI publishes an annual report documenting per-mile operating costs, which were

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[24] Wayne D. Cottrell. "Performance Metrics Used by Freight Transport Providers," September 30, 2008.

[25] W. Ford Torrey, IV, and Dan Murray. "Analysis of the Operational Costs of Trucking." American Transportation Research Institute, September 2016.

[26] "Measuring Carrier Performance - Inbound Logistics." Accessed March 24, 2017. (enumerated web address: http://www.inboundlogistics.com/cms/article/measuring-carrier-performance/).

[27] Wayne D. Cottrell. "Performance Metrics Used by Freight Transport Providers" September 30, 2008.

[28] Katherine Turnbull. "Performance Measurement of Transportation Systems: Summary of the Fourth International Conference," 2013.

[29] Wayne D. Cottrell. "Performance Metrics Used by Freight Transport Providers" September 30, 2008.

[30] Ibid.

$1.593 per mile in 2015.[31] The Operational Costs of Trucking report allows carriers to benchmark their relative performance in numerous cost centers, including, fuel costs, truck/trailer lease or purchase payments, repair and maintenance, insurance premiums, permits/licenses, tires, tolls, driver wages, and driver benefits.[32] Finally, attention to operating margins is a crucial measure in the private sector.[33]

Safety

Safety is of crucial importance and directly influences operational efficiency and financial measures. Government-monitored Compliance, Safety, Accountability (CSA) scores, which are used to assess carrier safety, affect carriers in numerous ways, including the following:

- Carriers with "bad" CSA scores may be less likely to receive shipper contracts.
- Insurance rates may be affected by CSA scores.
- Plaintiff attorneys may use CSA scores to demonstrate carrier negligence or culpability.
- Carriers with "bad" CSA scores are prioritized for more frequent inspections.[34]

Safety performance measures track safety performance in a company, which helps identify and address risks. Safety performance measures typically fall into the following categories: crashes, driver injuries, and CSA impacts. Crash performance measures may be adjusted by time or by vehicle miles traveled (VMT) to account for exposure to risk. Crash performance measures may also be considered in terms of whether a crash is preventable or DOT reportable.[35] Driver safety performance measures relate to driver injuries. Injury rates may be adjusted for exposure by considering injuries per employee or injuries per hours worked. The financial effect of driver injuries is also assessed in performance measures such as worker compensation costs as a percentage of revenue. Speeding events are also tracked.

Most safety data are generated from State and federal databases which are almost exclusively predicated on historical data. It is also well known that the crash and violation data is often missing or poorly defined across the hundreds of reporting jurisdictions.

While researchers have tried to correlate externalities ranging from traffic congestion, construction activities and work zones, GDP indices, and even FICO scores, the extreme complexity of transportation safety inputs makes it challenging at best. Simple correlations and trend analyses – based on historical data is commonplace.

[31] W. Ford Torrey, IV, and Dan Murray. "Analysis of the Operational Costs of Trucking." American Transportation Research Institute, September 2016.

[32] Ibid.

[33] Wayne D. Cottrell. "Performance Metrics Used by Freight Transport Providers," September 30, 2008.

[34] Caroline Boris, and Dan Murray. "Assessing the Impact of Non-Preventable Crashes on CSA Scores." American Transportation Research Institute, November 2015.

[35] DOT-reportable crashes involve at least one fatality, injury where an individual is taken to a medical facility, or a vehicle being towed because of property damage incurred in the crash. A preventable crash is defined as a crash "that could have been averted but for an act, or failure to act, by the motor carrier or the driver." (49 CFR 385.3)

CHAPTER 7. SHARING OF DATA BETWEEN PUBLIC AND PRIVATE SECTOR

Public transportation agencies can consider arrangements with private data firms to obtain data needed for behavioral supply chain freight models. These arrangements can provide agencies with access to data with large samples or new attributes, but there are also challenges around data privacy. The key concepts around data privacy from the literature are provided in Appendix A.

PROPRIETARY DATA AND PRIVACY ISSUES

The internal and external sharing of data is crucial to most business operations. It forms the basis for most business decision-making processes and models. Conversely, the protection of these data, which are often proprietary in nature, is essential to reducing both personal and professional risk and liability. The data management landscape has shifted over the last decade: technological advances associated with collecting business information have been exponential, leading to a massive increase in the amount of data that is generated, stored, and distributed. The concept of data mining has data analysts synthesizing and analyzing seemingly unrelated datasets for patterns, trends, and insights in ways that were never previously imagined. Data mining has also created new areas of privacy concern since sensitive information can often be discerned through cross-referencing otherwise innocuous datasets. Unfortunately, the speed of data generation, analysis, and monetization has outpaced the knowledgebase for data protection.

Maintaining business confidentiality and data privacy is a well-understood necessity for individual firms competing in a free market. Like most other industry sectors, the trucking industry develops and manages data that are often considered sensitive and proprietary. The myriad business records that seem of interest to certain outside parties may include: balance sheets, income statements with profits and losses, accounts payable and receivable, customer and cargo information, equipment inventories, depreciation schedules, compensation schedules, routes/lanes, and real-time vehicle location information. In addition to these, carriers generate and maintain extensive safety and economic forecasting data. The ultimate objective of data collection is for supply chain firms to operate a safe and profitable business. However, many in the trucking industry are concerned that data disclosure pressures are growing, particularly due to technology developments and an unpredictable regulatory landscape[1].

VEHICLE-LEVEL DATA ISSUES

Vehicle-level data privacy concerns are based on devices that exist within vehicles or devices that are external to vehicles. In addition, the use of event data recorder information collected

[1] John Sommers II, "Some Carriers Worry How Proposed Safety Scoring Could Affect Them," Transport Topics, September 12, Accessed September 13, 2017. (enumerated web address: http://www.ttnews.com/articles/some-carriers-worry-how-proposed-safety-scoring-could-affect-them).

from trucks is highly controversial, and has led to concerns ranging from data privacy to abuse of discovery.[2]

Concerns also exist around providing detailed cargo/commodity data. The U.S. Department of Justice has indicated that cargo theft may exceed $100 billion dollars annually. Providing real-time latitude-longitude data on trucks and commodities would greatly enhance a perpetrator's ability to identify valuable cargo in a moving truck.

Concerns raised by industry from these unit-level privacy examples not only convey the proprietary nature of data, but also rationalize concerns toward certain legal consequences that may evolve from data disclosure such as the use of anonymized data in court cases by plaintiffs' attorneys.

MACRO SUPPLY CHAIN DATA ISSUES

Supply chain data typically include inventory level, sales data, order status for tracking and tracing, sales forecasts (or other forecasts), and production/delivery schedules. Data sharing among supply chain partners is a critical requirement to ensure greater efficiency for business partners. Most business contracts include clear language that defines what data are considered proprietary, who owns the proprietary data, how it must be managed and protected, and what legal consequences will ensue if the data are deliberately or accidentally released.

Anecdotally, industry concerns relating to data access have classically been rank-ordered as follows:

1. Civil litigation impacts.
2. Competitor access to proprietary data.
3. Government access for regulatory compliance.

Data sharing with government is a growing business concern given the increasing use of electronic data, with few legal and technical tools for protecting such data. Without these protections, the freight industry has been extremely wary to participate in government research programs where industry data could be invaluable. At the same time, without real-world industry data, public sector agencies have difficulty justifying the transportation attention and investment desired by industry.

Government often has a legitimate need to obtain industry data, but State and federal laws make it challenging for government agencies to enter legal arrangements to protect proprietary data. A patchwork of laws exist that seek to protect certain data from disclosure; while other laws require release of data to support the concept of transparent government. The most prominent and widely encountered laws in this realm are described in the following sections.

[2] Schmitt-Cotta, 2005. Discovery abuse may be defined as intentional misreading of EDR data by expert witnesses to bolster the claims of plaintiffs.

FREEDOM OF INFORMATION ACT

One of the programs that has impacted the sharing of industry data is the Freedom of Information Act (FOIA). FOIA is a federal law enacted in 1966 and codified at 5 USC § 552 et seq.,[3] which provides individuals with the opportunity to view public documents held by federal government agencies. Any individual can make a request for access to any public document, data, or information held by a government agency. The agency must respond to requests per the agency's procedures[4] and provide the requester with access to the requested information unless a specific data protection exemption applies. Because FOIA allows individuals to request information about third parties, a FOIA request to a federal agency involved in collecting, storing, or analyzing trucking industry data as part of a U.S. Department of Transportation (USDOT) program presents a potential threat to the confidentiality of proprietary information of the participants.

FOIA requests can be legally rejected in several situations. The primary reasons for denial that would relate to a USDOT database of proprietary industry data include the following:

- **Physical Possession of the Requested Data**. FOIA generally requires the release of any data possessed by an agency. A general legal interpretation is that data obtained under the sponsorship of an agency, but physically stored outside of the agency, would likely be protected against a FOIA request/release.
- **Using one of the Nine FOIA exemptions**. FOIA Exemption #4—Trade Secrets and Confidential Commercial Information reflects Congress' recognition that public access to some information, such as commercially sensitive data, would adversely affect the ability of government and private parties to collaborate. Exemption #4 protects information in agency records from mandatory disclosure provisions of FOIA if it constitutes trade secrets and commercial or financial information obtained from "a person" and is privileged or confidential. This information is protected if it is privileged or confidential, and obtained from a person.[5] For the purposes of Exemption #4, a "person" is defined as an individual, partnership, corporation, association, or public or private organization other than an agency,[6] and thus would include a freight company or other intermediary, customer, seller, or other participant participating in a USDOT program IF the data are formally classified as "Trade Secret." The "confidential information" Exemption #4 is available when disclosure will either: 1) impair the government's ability to obtain

[3] The FOIA Regulations are codified at 26 CFR Part 16 (2017). A copy is available at https://www.gpo.gov/fdsys/pkg/FR-2017-01-04/pdf/2016-31508.pdf.

[4] The following are citations to FOIA regulations promulgated by two agencies pertinent to a U.S. DOT database of industry data – together with some useful website summaries:

- Department of Transportation: 49 CFR Part 7 About FOIA.(enumerated web address: https://www.transportation.gov/foia).
- Department of Homeland Security: 6 CFR Part 5 Department of Homeland Security Homepage. (enumerated web address: https://www.dhs.gov/).

[5] 5 USC § 552(b)(4).

[6] 5 USC § 551(2).

necessary information in the future; or 2) cause substantial harm to the competitive position of the person providing the information.[7]

- **Voluntarily Provided Data**. Case law has recognized and supported the increased protection of private sector data that was provided voluntarily by industry. Recognizing the unique nature of public-private partnerships, legal precedents have favored denying requests that could harm or undermine voluntary and innovative arrangements between the business community and government agencies.

Additional federal laws that have some nexus to data protection or disclosure include the following:

- **Privacy Act of 1974 (5 USC §552a)**. The Privacy Act protects individual data. This act allows government agencies to protect certain data that relates to specific individuals.
- **Drivers Privacy Protection Act (18 USC § 2721)**. The Drivers Privacy Protection Act (DPPA) is more specific to truck driver data. It was enacted to protect individuals' right to privacy, guarding individuals' information from improper disclosure or use.[8] In practice, DPPA requires states to protect information in an individual's motor vehicle record (MVR) and delineates permitted uses for MVR data. DPPA permitted uses of MVR data include verifying accuracy of personal information and legitimate State uses related to motor vehicle safety.[9] That said, individual drivers can sign releases that allow the collection and use of specific data for research and other purposes.
- **Fair Credit Reporting Act (15 USC § 1681 et seq.)**. The Fair Credit Reporting Act (FCRA) mandates that credit reporting agencies follow reasonable procedures to ensure that consumer privacy and accuracy of information is ensured.[10] Most financial data, including secondary data related to an individual's personal information from MVRs, is protected by FCRA requirements.

STATE SUNSHINE LAWS

Similarly, many states have laws regulating the release of public records. These laws vary by State.[11] Most State sunshine laws have exemptions for personal privacy, law enforcement, and commercially valuable information.[12] Provision of commercially valuable information to

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[7] Id. at 770.

[8] Center, Electronic Privacy Information. "EPIC - The Drivers Privacy Protection Act (DPPA) and the Privacy of Your State Motor Vehicle Record." Accessed March 17, 2017. (enumerated web address: https://epic.org/privacy/drivers/#cases).

[9] Ibid.

[10] Center, Electronic Privacy Information. "EPIC - The Fair Credit Reporting Act (FCRA) and the Privacy of Your Credit Report." Accessed March 17, 2017. (enumerated web address: https://epic.org/privacy/fcra/).

[11] "Open Records Laws A State by State Report.pdf." Accessed March 17, 2017. http://www.naco.org/sites/default/files/documents/Open%20Records%20Laws%20A%20State%20by%20State%20Report.pdf.

[12] "Freedom of Information Laws | Reporters Committee for Freedom of the Press," October 28, 2011. (enumerated web address: https://www.rcfp.org/first-amendment-handbook/freedom-information-laws).

government agencies would require a state-by-state investigation of relevant laws to ensure information is applicable for exemption from public access.[13, 14]

INSTITUTIONAL ISSUES AND OTHER CONSIDERATIONS

This section includes additional and important institutional data issues that extend beyond the previously cited legal and regulatory concerns. The following issues can affect aspects of a USDOT data collection program:

- **Revenue/Funding Expectations**. Based on historical experience, it is plausible that the private sector will request or expect financial compensation for its private sector data. Unless the direct benefits from the sharing of proprietary data are direct and immediate, private firms will be reluctant to utilize their own resources to create and maintain a data-sharing program.
- **Timeline Expectations**. While government agencies would not likely require real-time receipt of industry data, numerous externalities could affect when data is shared. Syncing timelines and schedules for data receipt and distribution will be important, and ultimately formalized and automated. Once in place, it will be challenging to change any metrics and outputs.
- **Lack of Subject-Matter Expertise for Data Privacy Issues**. Most public-sector transportation stakeholders are unaware of legal, contractual, and competitive issues associated with proprietary data. Information on issues related to sensitive data and information should be understood by transportation agencies.
- **Data Continuity**. For the USDOT, data continuity is extremely important, as any lapses or changes in data could dramatically affect data products and services. Since business models constantly change (firms merge, change data systems, or go out of business), the USDOT will need to develop and implement data redundancy plans. This need to maintain redundant technology systems and redundant data feeds could come with a high cost.
- **Standardized Agreements**. Standardized agreements and contract templates should be developed immediately for future use to reduce processing and negotiation time. A sample nondisclosure agreement is provided in Appendix B. Developing and submitting these generic tools for broad scrutiny by both government and industry legal representatives could create solid vehicles for information-sharing and partnerships, and send a positive message to industry that government is a willing signatory.

DATA-SHARING REQUIREMENTS AND EXPECTATIONS

The topic of data privacy requires new and innovative agreements. This need is based on growing concerns surrounding proprietary data protection—including who shares data, how the data are protected, how and when access is authorized, and voluntary data sharing between

[13] Ibid.

[14] Summaries of State laws relating to public access to government collected information can be found at [Open Government Guide](https://www.rcfp.org/open-government-guide) (enumerated web address: https://www.rcfp.org/open-government-guide).

private industry and government agencies—and the rise in data theft. These agreements will likely include variations of the following requirements:

- **Legally Binding**. All agreements/contracts between industry and government must include legal, financial, or criminal consequences should the agreement be violated. Several public agencies or academic institutions will not or cannot sign agreements that generate liability; in some cases, these legal positions are underpinned by State law or even constitutional clauses. Such entities may not be legally able to protect sensitive industry data.
- **Clear Ownership Clauses**. The private sector will likely not relinquish data ownership rights. This means that data-sharing arrangements will provide a use license and clear guidance on how the data can/cannot be used, and by whom. These restrictions may conflict with both State and federal law (e.g., challenges with the Confidential Information Protection and Statistical Efficiency Act) which may allow or require the sharing of certain data across agencies that may not be a party to the data-sharing agreement (DSA).
- **Clear Data Usage Restrictions**. Many DSAs explicitly state who cannot use the data, and what uses are not appropriate or authorized. Even when data are anonymized so that individual parties cannot be identified and harmed, entire sectors and classes may still be affected. Industry is aware of such large-scale impacts and is hesitant to participate in DSAs that may create such negative impacts.
- **Use of Trusted Third Parties**. Considerable industry support exists for the use of "trusted third parties" who can act as reliable and knowledgeable stewards for proprietary industry data and related data-sharing partnerships. These entities must possess industry subject-matter expertise to ensure that certain data are not shared or synthesized inappropriately; must be able to successfully negotiate data-sharing contracts with industry; and provide technical support to government agencies in terms of analysis and interpretation.

A case study in successful private sector data sharing with the government is provided in Appendix C.

APPENDIX A. DATA PRIVACY LITERATURE—KEY CONCEPTS

Bibas (1994)[1] examined solutions to data privacy issues at the macro and micro levels. The macro, or centralized level solutions cited by the author are government based and do not cater to any one individual group or situation. The first solution offered by the author is regulatory and legislative in nature. These include federal provisions that would tighten restrictions on the transaction of data (or the security of data) and may also allow one or more administrative agency the capability to regulate data privacy. The second solution suggests constitutional protections of privacy and property in relation to data. Finally, it is suggested that the judicial system determine which data merits protection on a case-by-case basis.

Another concept of data protection is introduced by Nelson (2004)[2], who proffers a concept relating to the relationship between technology, privacy, and government. Nelson identifies the dual role of government and the role of technology in addressing privacy issues. A first role of government is as the protector of privacy by means of legislative and regulatory functions. Applied to the private industry data held by the U.S. DOT, laws should protect the data-sharing parties, and parties whose data could be collected, through coercive means. The threat of government penalties will facilitate acceptable data-sharing practices as all parties of the supply chain strive for compliance.

Parker (2003)[3] suggests that data privacy policies for businesses should address four key issues that will improve overall business in a method that can be applied to trading partners. Under the authors guidelines, trading partners would first assess their own privacy policies and procedures to not only protect their data, but more importantly, the data of their trading partners. Secondly, when the decision is made to enter into a DSA, trading partners should form a plan to comply with the data privacy needs of the other firm and with any regulations that are in place. This includes dedicating labor resources to ensuring compliance is met for internal and external data privacy policies. This is followed by implementation of the plan, and finally verification.

In the current global economy, it is often the case that supply chains include overseas manufacturing. Klosek[4] (2005) discusses risks to personal information held by offshore businesses that provide outsourced goods and service. Several steps that trading partners may want to take to manage the risk of data privacy breaches include:

- Investigation of the offshore trading partners' data privacy and security policies.
- Investigation of data privacy history and complaints.
- Investigation of methods used for protecting data.

[1] Bibas, Steve A., (1994). A Contractual Approach to Data Privacy. Harvard Journal of Law and Public Policy, Spring 1994.

[2] Nelson, Lisa. (2004). Privacy and Technology: Reconsidering a Crucial Public Policy Debate in the Post-September 11 Era.

[3] Parker, Robert G. (2003) How to Profit by Safeguarding Privacy.

[4] Klosek, Jacqueline. (2005). Data Privacy and Security Are a Significant Part of the Outsourcing Equation.

It is finally recommended that an exit strategy be developed regarding data privacy in the case that a trading partnership ends with the private firm.

APPENDIX B. SAMPLE NONDISCLOSURE AGREEMENT

In contemplation of a relationship between __________________________ and ____________________________, __________________________ (“Disclosing Party”) has disclosed or may disclose to __________________________ (“Receiving Party”) certain “Proprietary Information” as defined below. Receiving Party agrees to use Proprietary Information only for those purposes expressly permitted by this Agreement. All Proprietary Information is and will remain the sole property of the Disclosing Party.

In consideration of any disclosure, the parties agree as follows:

1. For the purposes of this Agreement, “Proprietary Information” shall mean information, whether or not originated by Disclosing Party, which is used in Disclosing Party’s business and is (i) proprietary to, about, or created by Disclosing Party; (ii) gives Disclosing Party some competitive business advantage or the opportunity to obtain such advantage, or the disclosure of which could be detrimental to the interests of Disclosing Party; (iii) designated as Proprietary or Confidential Information by Disclosing Party, or from all the relevant circumstances should reasonably be assumed by Receiving Party to be confidential and proprietary to Disclosing Party; or (iv) not generally known by non-Disclosing Party personnel.

2. Both Parties agree that the Proprietary Information shared in conjunction with this Agreement constitutes information exempted from disclosure under the Freedom of Information Act as defined and pursuant to 5 USC 552(b).

3. For example, Proprietary Information shall include, without limitation, the following types of information and other information of a similar nature related to Disclosing Party’s business, whether or not designated as confidential or reduced to a writing, record, or tangible embodiment:

    a. Computer Software. Computer software of any type or form in any stage of actual or anticipated research and development, including but not limited to programs and program modules, routines and subroutines, processes, algorithms, design concepts, design specifications (design notes, annotations, documentation, flowcharts, coding sheets, and the like), source code, object code and load modules, programming, program patches and system designs;

    b. Other Proprietary Data. Information relating to proprietary rights prior to any public disclosure thereof, including without limitation, the nature of the proprietary rights, production data, technical and engineering data, test data and test results, the status and details of research and development of products and services, and information regarding acquiring, protecting, enforcing and licensing proprietary rights (including patents, trademarks, copyrights, and trade secrets);

    c. Business Operations. Internal personnel and financial information, vendor names and other vendor information (including vendor characteristics, services and agreements), purchasing and internal cost information, internal services and operational manuals, the manner and methods of conducting business, and supply chains and transportation routes;

d. Marketing and Development Operations. Marketing and development plans, price and cost data, price and fee amounts, pricing and billing policies, quoting procedures, marketing techniques and methods of obtaining business, forecasts and forecast assumptions and volumes, and future plans and potential strategies which have been, are being discussed or are about to be discussed; and

e. Customers. Names and contact information of customers and their representatives, contracts and their contents and parties, customer services, data provided by customers and the type, quantity and specifications of products and services purchased, leased, licensed or received by customers or clients of Disclosing Party.

4. Proprietary Information shall not include information which Receiving Party can document (a) is in the public domain through no fault of its own, (b) was properly known to it, without restriction, prior to disclosure by Disclosing Party, (c) was properly disclosed to it, without restriction, by another person with the legal authority to do so, or (d) has been independently developed by employees or agents of Receiving Party who have not had direct or indirect access to, or knowledge of, Disclosing Party's Proprietary Information.

5. Receiving Party is hereby permitted to use the Proprietary Information solely for the purpose(s) of
____
____
____________________ as addressed in Exhibit A).

6. In the absence of express prior written permission granted by the Disclosing Party, the Receiving Party shall NOT: directly or indirectly disclose, display, provide, transfer, or otherwise make available all or any part of the Proprietary Information to any person or entity at any time during the period in which Receiving Party has access to the Proprietary Information or thereafter; make copies of the Proprietary Information or any portion of it; reverse-engineer, decompile or disassemble the Disclosing Party's software or Proprietary Information or attempt to use Disclosing Party's software in any form other than machine-readable object code; disclose any Proprietary Information to any third party, except to those employees or dedicated consultants of the Receiving Party who (a) need to know such information in connection with the potential transaction between the parties and (b) are bound to Receiving Party by a duty of confidentiality similar to Receiving Party's duty hereunder. If the Receiving Party is required by applicable law or legal process to disclose any Proprietary Information, and such law or process does not prohibit notification to Receiving Party, the Disclosing Party will first use best efforts to inform Disclosing Party of any such proposed disclosure, and give the Disclosing Party a reasonable opportunity to contest such requirement.

7. Nothing in this Agreement shall be construed as granting or conferring any right by license or otherwise upon Receiving Party.

8. Upon termination of the contemplated relationship, or if it fails to commence, upon request by the Disclosing Party, Receiving Party will promptly return to Disclosing Party all Proprietary Information and all copies and extracts thereof.

9. Receiving Party will promptly notify the Disclosing Party of any unauthorized release of any portion of the Proprietary Information.

10. Receiving Party will promptly notify the Disclosing Party of any third-party request for release of any portion of the Proprietary Information.

11. Nothing in this Agreement shall be construed as obligating the Disclosing Party to disclose any information or to negotiate or enter into any agreement or relationship, including the relationship in contemplation when this Agreement was executed.

12. Enforcement

    a. Any dispute, controversy or claim arising out of or relating to this Agreement, or the breach, termination or invalidity thereof shall be submitted to final and binding arbitration under the Commercial Dispute Resolution Procedures of the American Arbitration Association. Judgment upon the arbitration award or decision may be entered in any court having jurisdiction. The arbitrators' award may include compensatory damages against either party but under no circumstances will the arbitrators be authorized to, nor shall they award consequential, incidental, special, punitive or multiple damages against either party.

    b. Notwithstanding the above, the parties acknowledge that Proprietary Information is unique and valuable, and that disclosure in breach of this Agreement will result in irreparable injury to Disclosing Party for which monetary damages alone would not be an adequate remedy. Therefore, the parties agree that in the event of a breach or threatened breach of confidentiality, the Disclosing Party shall be entitled to seek an equitable remedy, including without limitation, specific performance, injunctive or other equitable relief. Any such equitable remedy shall be in addition to monetary damages or other legal remedy awarded by a court having jurisdiction.

13. This Agreement shall be construed and interpreted in accordance with the laws of [insert name of State agreed by the parties], without regard to its conflicts of laws principles.

14. This Agreement may be modified or waived only in a writing signed by both parties. If any provision is held to be unenforceable, such provision will be limited or deleted to the minimum extent necessary to allow the remaining terms to remain in full force and effect.

15. This Agreement is the complete and exclusive statement of the mutual understanding of the parties and supersedes and cancels all previous written and oral agreements and communications with respect to the subject matter of this Agreement.

16. This Agreement may be executed on paper or electronically (fax or electronic document attached to e-mail) in one or more counterparts, each of which will be deemed an original, but all of which together will constitute one and the same instrument.

Acknowledged and agreed:

By:	Title:	Date:
By:	Title:	Date:

APPENDIX C. A CASE STUDY IN SUCCESSFUL PRIVATE SECTOR DATA SHARING WITH GOVERNMENT

Approximately 15 years ago, Federal Highway Administration (FHWA) approached the American Transportation Research Institute (ATRI) about obtaining sensitive industry data in the form of truck Global Positioning System (GPS) position data. FHWA had earlier attempted to obtain this information using a consultant, but was unsuccessful. After several meetings with FHWA to understand the purpose and outcomes of providing such industry data, ATRI felt comfortable that the objective to populate national freight transportation planning products with real-world empirical data was an appropriate use. At that time in 2002, ATRI obtained data from approximately 25 large carriers, and began building and beta-testing the "freight performance measures" initiative. Since then, the number of carriers that ATRI receives data from can be counted in the thousands.

ATRI has now managed FHWA's Freight Performance Measures (FPM) initiative – originally titled "*Real-Time Performance Measures in Freight-Significant Corridors*" – since 2002. In that time, ATRI worked closely with multiple FHWA personnel to expand and refine the FPM system into a large, well respected freight data architecture program that has been used by hundreds of entities for freight planning, management, and research. While substantial credit goes to FHWA for its guidance and sponsorship, dozens of universities, public sector agencies and subject-matter experts have also contributed to the development and utility of the FPM program and its various components.

UTILIZING TRUSTED THIRD PARTIES

As background, ATRI, an award-winning leader in transportation-related research, was first created by the trucking industry in 1954. ATRI is a 501(c)(3) not-for-profit research organization headquartered in Arlington, Virginia with regional offices in California, Georgia, New York, and Minnesota.

As an autonomous member of the American Trucking Associations Federation, ATRI benefits from the broad support of the trucking industry and its members. The Federation represents over 40,000 motor carriers through dozens of affiliated associations in all 50 states. Because of ATRI's prominence within the trucking industry, public sector agencies turn to ATRI for trucking-related research, particularly when industry insight and cooperation is essential to the success of the project. For this reason, ATRI could initially assist FHWA in obtaining sensitive industry data, anonymize that data, and design/generate multiple data products.

FHWA NEEDS AND EXPECTATIONS FOR A TRUSTED THIRD-PARTY INTERFACE

ATRI has now received a dozen data-related contracts or subcontracts to support FHWA's freight planning objectives. In both sole-source and competitively bid contract processes, ATRI met the following requirements:

Data Access

The FPM program must ensure access to industry data over an extended period. A transportation data program such as FPM requires a stable and consistent data source. FHWA's existing program has maintained, and increased, its data access through ATRI for nearly 15 years. Continued and sustainable data access is a paramount objective for FHWA and other agencies who require data stability and consistency in pursuit of long-term planning and operations. Two critical sustainability factors should be considered when making a public-sector investment in truck GPS probe data.

A key factor is "institutional access." Simply put, the rules and policies governing data use can change overnight, which can create challenges for a program that seeks to utilize GPS probe data for long-term analysis and decision-making. While data streams today may generate from secondary communication providers, the current legal landscape confirms that raw data from the "probe vehicle" marketplace ultimately belongs to the data generators (e.g., truck owners and operators), as they are the legal owners of the data that generates from their communications equipment. Consequently, motor carrier support/consent becomes a critical component of data access. Every few years, ATRI formally contacts trucking industry executives to reconfirm their support of ATRI accessing their data as a "trusted third-party" interface.

Considering the requirements, ATRI is uniquely qualified to access proprietary industry data, and ATRI's carefully designed "DSAs" go far beyond truck GPS data. ATRI also maintains large and sought-after data relating to safety, insurance costs, commodities, technology utilization and industry financial data. Thus, ATRI can access and cross-reference highly sensitive data because ATRI will ensure that the data is both protected and used for appropriate performance measurement, planning and research purposes.

Data Continuity/Sustainability

The truck GPS data feeds, which are now typically delivered in real-time, are based on complex but technically sound and proven DSAs or nondisclosure agreements that allow parties to candidly discuss and strategize on FPM requirements. Recognizing that data access could be endangered from the unauthorized use of FPM data by outside parties, ATRI worked closely to have its raw data classified as "trade secret" by three different States' legal authorities. This additional firewall further protects the raw data from State "sunshine laws" and other FOIA-like requests.

FPM System Design and Management

The freight performance measurement program requires sophisticated hardware, including terabytes of space, to store and analyze significant amounts of data. Backup and restore services, data and virtual machine archiving, storage array setup and management, remote desktop services, firewall and Internet Protocol networking and data transfer services have all been proven to be critical components of the FPM system architecture. Ongoing technical and maintenance support is also necessary. Additionally, GIS software is essential for managing, analyzing, and reporting spatial data in a manner that is useful to the public sector.

ATRI has spent the last 15 years building, managing, and evaluating hardware and software components for the FPM program. While many existing commercial GIS software packages are used for FPM processing, in several instances, ATRI worked with vendors to develop customized tools such as the truck GPS "snapping tool" or developed its own formulas, algorithms, and processing tools for conducting the myriad different analyses that have become key components of FPM.

System development and management are not the core responsibilities of the U.S. DOT, nor the many other entities that utilize the FPM data; this function is most appropriately contracted to the private or not-for-profit sectors.

Converting Proprietary to Public

To ensure that transportation planning agencies can fully benefit from private sector data, FPM outputs and services must not be proprietary. While nearly all "raw data" is protected by ATRI, FPM's processed outputs should be made publicly available. For example, a product such as an aggregated truck trip table that shows the most common origin and destination locations in a given geography/timeframe would not have the same protections as the individual trips that were aggregated to produce the table.

Understanding Public Sector Transportation Planning Activities

To design and package FPM products and services for transportation planning purposes, a trusted third party must have more than a rudimentary understanding of the public-sector planning process and its related data needs. At all jurisdictional levels, there are unique and discreet planning requirements and products;

Industry Expertise Needed to Analyze Outputs

National freight performance measurement, freight system planning, and freight transportation research are data-driven activities. These activities are also indicators/surrogates for freight activity, truck flows, commodity flows, truck impediments, air quality impacts and truck parking requirements. Intimate familiarity with freight systems and data will provide maximum utility to FHWA and its customers.

FPM Users

ATRI's expertise in the above-referenced requirements, with an emphasis on transportation planning and freight systems, has resulted in long-standing FPM-oriented relationships with the following range of customers:

- Federal government:
  - U.S. Department of Transportation, FHWA.
  - U.S. Department of Homeland Security, Customs and Border Protection.
  - U.S. Department of Agriculture.
- State government:

  - 38 State DOTs.
- Local government:
  - 47 MPOs.
- Private sector:
  - Consultants.
  - Technology vendors and suppliers.
  - Trucking companies.
  - Site selection and engineering firms.
- Academia:
  - More than 20 national and international academic institutions.

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