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Estimating the Monetary Benefits of Reducing Delays on Heavily Trafficked Truck Freight Corridors in Georgia

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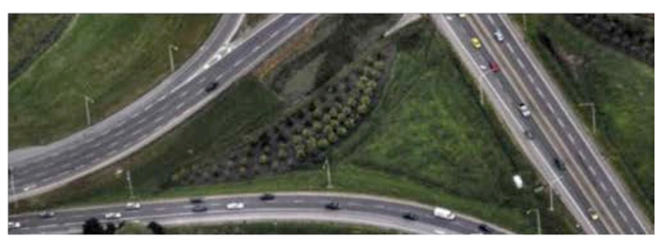

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Estimating the Monetary Benefits of Reducing Delays on a Heavily Trafficked Truck Freight Corridor

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Executive Summary

Project Motivation and Overview: A good deal of literature in recent years has focused on the financial costs to both freight shippers and carriers from increased traffic congestion, notably along the nation's major freight-carrying highways. Federal attention in the form of the 2012 MAP-21 legislation (and again in the December 2015 FAST Act which supersedes it) motivated the present study, which was carried out to investigate the potential for existing methods and datasets to quantify such congestion induced delay costs on a corridor-specific basis. Specifically, the research effort was motivated by a lack of commodity-specific, and by implication industry-specific detail about the types of freight being transported over specific, highly trafficked highway corridors. To this end the present study focused first of all on measuring the market value of goods being moved within an example corridor, and then upon estimating the monetary costs of traffic congestion as it affects such corridor-dependent, and industrial sector-specific freight flows.

Making use of typically available datasets, a set of spatially and sectorally detailed commodity flows are estimated and converted to a set of truck class-specific origin-to-destination movements. These truck movements are then input to a corridor-oriented and congestion sensitive, multi-class traffic network assignment (i.e. routing) model. Iteration to a stable equilibrium between the resulting commodity distribution models and multi-truck class route assignment model is then carried out within a popular geographic information system software, yielding a set of county or sub-county commodity flow matrices and their associated, origin-to-destination based (O-D) trip time and monetary cost estimates. A select link analysis tool is then used to identify which of these O-D flows are likely to make use of a specific, highly trafficked Interstate highway, and what classes of trucks are likely to be used to carry the goods being transported over it. By comparing the resulting travel times and also estimating the variability in such times, the monetary costs of congestion delays associated with corridor flows are estimated.

Spatial Disaggregation of Commodity Flows: To accomplish this a significant effort went into disaggregating potential corridor-based truck movements both spatially and sectorally. This involved identifying the origin-destination-commodity (and subsequent truck class) flows taking place within the Georgia portion of the Interstate-85 highway corridor. A set of 43 commodity class specific freight origin-to-destination flows were estimated based on a county disaggregation of such flows for a six state region of the south-eastern United States. These flows were assigned to the Interstate-85 corridor, with a focus on truck movements that pass into, out of, within, or through the state of Georgia. One product of this effort is an estimate of the dollar value of freight moved through this freight significant corridor, a statistic that has proved difficult to obtain from past studies: and which, as expected, was much higher within this corridor than the value of freight moved regionally or nationally.

Estimating The Costs of Truck Travel Delays: To obtain estimates of the congestion-impacted delays associated with the corridor's truck movements, model estimated travel costs were compared against uncongested (or "free flow") trip costs. Using data from 2007 to test the modeling framework, corridor traffic induced delays summed over all origin-to-destination truck trips yielded an estimate corridor delay cost on the order of $1.6 million a day - with the major contributor the extra operating hours associated with delays in moving through metropolitan Atlanta. These were principally non-local flows that made use of Interstate 85 within Georgia for some portion of their trips. Based on an extensive review of the recent literature on truck freight value of time, the issue of on-time vehicle arrivals was found to be a significant component of delay-induced business logistics costs. Based on values of trip time reliability found in this literature, and grounded in estimates of the variability of corridor-using travel times, example scenarios produced estimates of these additional business logistics-related delivery costs. Combining the estimated extra trip time costs with those due to trip time unreliability, scenarios reported in Chapter 5 of this report yield estimated congestion-induced transportation costs of between 7% and 8.2% of free-flow, uncongested truck operating costs. While these valuations are meant here as illustrative only (given the need to combine a number of different data sets, and numerous literature-provided model parameter values and assumptions in order to generate the results), they demonstrate the importance of such over-the-road costs to both the trucking industry and to businesses using trucking to both deliver their input materials and distribute their finished products. Given the well-established non-linear impacts of congestion on trip times under fixed highway capacities, and the considerable increase in congestion levels already evident and also projected for this and other freight significant corridors in the south-eastern United States, such costs are likely to play an important role in both regional and national economic competitiveness over the next two to three decades. The model developed during the project should prove useful as a long range, sketch planning tool, including the ability to compare results across different corridors under different model-imposed parameters and assumptions. However, given the wide range of current empirical reporting on a number of these parameters and assumptions, enhanced and more localized data collection efforts are needed to support robust estimates of the time-impacted costs of trucking within a region’s freight significant corridors.

Chapter 1. Introduction

1.1 Study Purpose

Building on the Moving Ahead for Progress in the 21st Century (MAP-21) Act of 2012, the Fixing America's Surface Transportation (FAST) Act of December 2015 directs the Federal Highway Administrator to establish a National Highway Freight Network (NHFN) by strategically directing federal resources towards improved performance of the U.S. freight transportation system.[1] Recognizing that large sums of public money will be needed to achieve significant additions to the existing capacity of such corridors, transportation planners within both State Departments of Transportation (DOTs) and Metropolitan Planning Agencies (MPOs) will need to demonstrate the value of such expenditures within their own regions. This raises the issue of how to quantify the benefits of greater mobility, and notably the monetary gains associated with the travel time savings that typically represent the major proportion of the benefits associated with such capacity additions. Of particular interest to this present study are the benefits associated with time savings or losses associated with truck freight movements. Over the past three decades an increasing percentage of total travel time-related costs of movement have become associated with truck transport, which has grown even faster in terms of vehicle miles traveled than its passenger traffic counterpart.[2] For example, a recent estimate by Pierce and Murray (2014) attributed the loss of some 141 million truck operating hours to highway congestion in 2013, at a cost of over $ 9.2 billion.[3]

A better understanding of the mix of commodities moving over specific highways, both now and in the future is of considerable interest to transportation planners, who must assess pavement wear and tear, anticipate safety concerns, assess the impacts of traffic congestion on trucking costs, and understand the link between economic activity and highway capacity needs. However, while such estimates have been important to regional planning studies for decades, the ability to estimate a set of truck freight movements that capture both commodity class and vehicle type on a trip origin to destination basis, and to translate such trips into route or corridor specific traffic volumes continues to pose two significant challenges for would-be analysts, both of which are strongly tied to existing data limitations. First, existing data sources need to be combined and subjected to significant data modeling in order to provide the necessary details concerning how much and what sorts of commodities are being moved down a specific corridor. Second, once such estimates have been created, a good deal of uncertainty remains as to the monetary costs such delays represent, especially as such costs appear to vary a great deal,[4] depending upon, among other

[1] http://ops.fhwa.dot.gov/freight/infrastructure/nfn/index.htm
[2] https://www.fhwa.dot.gov/policyinformation/statistics.cfm
[3] Even so, such estimates do not include the potential downstream costs to those receiving (or not receiving) the freight in a timely manner, such as depletion of inventory, and missed deliveries on the next stage in a supply chain. These effects can be especially costly when such customers are operating on 'just-in-time' delivery schedules. See Chapter 4.
[4] Depending on the cost elements included, estimates in the recent literature range from less than $20 to as much as $341 per truck hour.

variables, the types of commodities shipped, the vehicle and cargo configurations used, shipment distances, scheduling requirements, contractual arrangements between the shipper, carrier and receiver, and the level and type of delays experienced while in transit.

In trying to improve upon this situation, the present study focused on developing a set of spatially and sectorally detailed, commodity-cum-truck class specific freight movement matrices as inputs to a corridor-oriented, and congestion sensitive traffic network (i.e. highway route) assignment model. The procedure then uses a select link analysis to identify which origin-to-destination (O-D) based commodity flows are likely to make use of a specific, highly trafficked Interstate corridor, and what class of trucks are likely to be used to carry such goods. Since we are dealing here with strategically important corridors, these O-D flows include significant truck movements coming into, moving out of, operating within, and passing through the state containing the corridor, with a different treatment applied to each set of flows. The highway traffic assignment method selected for this process is the origin-based, multi-vehicle class user equilibrium (OUE) model as implemented within Caliper Corporation's TransCAD GIS software, and which makes it possible for the analyst to retain the same set of O-D-Vehicle Class specific flows when comparing the impacts of two or more corridor improvement scenarios.

Results from this assignment model are fed back to a series of commodity-class specific flow matrix generating models until a stable set of flows and travel costs has been achieved along the Interstate corridor. A key component of the procedure, and of the resulting, travel time-based corridor performance measures, is the development of a suitable generalized travel cost measure based on a weighted combination of money plus travel time components, notably travel time variability. To the extent that existing data sources would allow, these time-based cost components were broken down by commodity as well as vehicle class, the former tied closely to the type of industry generating or attracting such goods movements. In doing so, the approach uses a review of the latest empirical evidence from the freight value of time literature to produce monetized benefit estimates that are grounded in travel behavior and spatial economic theory, including estimates that recognize the importance of consistent on-time delivery of goods. Modeling options experimented with at a number of stages in the modeling process are described in the relevant report chapters. Measures of corridor performance that can be derived from this modeling approach include an estimate of the approximate market value of those commodities being carried on the Interstate highway at the heart of the corridor (and entering, leaving, or traveling within the state of Georgia), as well as commodity based, dollar valued time losses resulting from increases in over the highway congestion.

1.2. Report Organization

The rest of the report is organized as follows:
Chapter 2: Study Corridor Definition and Selection
Chapter 3: Candidate Corridor Users: Origin-Destination Flow Matrix Generation
Chapter 4: Putting a Value on Corridor Truck-Freight: Multi-Class, Origin-Based and Congestion

Sensitive Assignment of Truck Trips
Chapter 5: Estimating Corridor Truck Travel Delay Costs

1.3 References

FHWA (2016) Fixing America's Surface Transportation Act or "FAST Act". Federal Highway Administration, U.S. Department of Transportation, Washington, Washington D.C. https://www.fhwa.dot.gov/fastact/

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Pierce, D. and Murray, D. (2014) Cost of Congestion to the Trucking Industry. American Transportation Research Institute. Arlington, VA. http://atri-online.org/2014/04/30/cost-of-congestion-to-the-trucking-industry/

Chapter 2. Study Corridor Definition

2.1 Introduction

When this project began the MAP-21 legislation of 2012 had placed corridors, and in particular freight corridors, front and center, requiring the US Department of Transportation (US DOT) to designate a national freight movement network that includes "major trade gateways and national freight corridors", and regional planning agencies to carry out "corridor or sub-area" planning as part of the federally supported statewide transportation planning process. The December 2015 FAST Act which supersedes this legislation continues its emphasis on strategic freight, including highway corridors. Figure 2.1 below shows those corridors identified as part of the Primary Highway Freight System (PHFS) within the state of Georgia, as part of a PHFS network of highways identified as "the most critical highway portions of the U.S. freight transportation system determined by measurable and objective national data". [5] The I-85/I-285 corridor, shown in Figures 2.1 and 2.2 below, was selected for empirical study. The rest of this chapter describes the characteristics of this corridor and why it was selected. This selection process is discussed in a generic manner, as a first step in an empirical analysis of the types of freight being moved over this and similar, strategically important Interstate highway corridors and of the economic costs of delays associated with such movements.

2.2 Literature on Corridor Definition and Guidelines

Corridor studies are becoming increasingly commonplace in transportation planning, whether dealing with freight, passenger, or mixed passenger-freight movements. These include a number of state DOT sponsored freight corridor and mixed passenger-freight corridor analyses (e.g. Adams et al, 2006 mid-western freight corridor study; Hadi, et al's 2010 study of Florida freeway freight corridors; IDOT/INDOT's 2012 study Illinois and Indiana passenger and freight corridors; Schneider and Fish's 2008 study of Wyoming's I-80 freight corridor; Liao's 2009 study of I-90/I-94 freight corridor performance between Minneapolis and Chicago; Southworth and Gillett's 2011 study of trucking performance along Georgia's I-75 corridor; North Carolina DOT's economic impact assessment of trucking activity and the shipment of goods along I-95 (CSI and ATRI, 2013); and Colorado DOT's mixed traffic congestion studies of the I-70 Mountain Corridor (CDOT, 2011; Louis Berger, 2014). An increased focus on freight significant corridors, and in particular on travel time-based performance measures, is also evident in federally supported research (for example, Mallett et al, 2006).

Such studies either implicitly or explicitly recognize the economies of scale associated with building network infrastructures that concentrate the movement of people and goods along high capacity routes

[5] http://ops.fhwa.dot.gov/freight/infrastructure/ismt/state_maps/states/georgia.htm

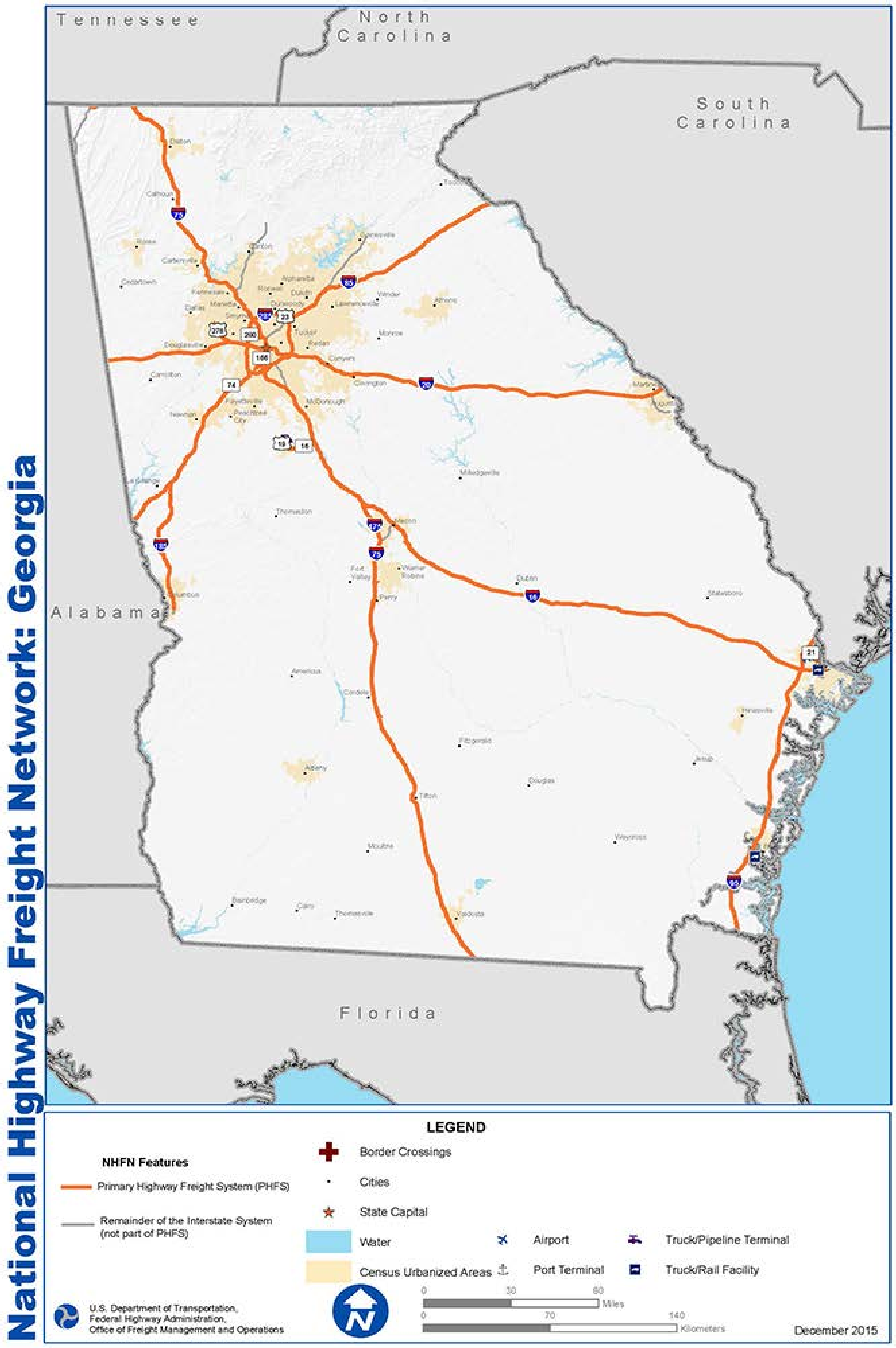


Figure 2.1 The Primary Highway Freight Network in Georgia
(Source: FHWA Office of Freight Management and Operations)

such as multi-lane highways. However, while a corridor-based approach to infrastructure investment has worked well for a number of decades, the combination of sustained traffic growth and increasingly constrained fiscal resources now places a burden of significant traffic congestion on many of these high-volume routes. One result of this has been the emergence of corridor management plans, as well as guidelines for carrying out corridor-based studies. And not coincidentally, the spotlight theme for the 2015 Transportation Research Board's (TRB) Annual Meeting was **"**Corridors to the Future".

But what do we mean by a transportation corridor, or more precisely for planning purposes, a corridor study area? An internet search throws up the following, more succinct, but single mode definition:

"*A transportation corridor is defined as a combination of transportation networks that link the same major origins and destinations. In simple terms, a transportation corridor is a linear pathway intended for a particular mode of transportation*." http://www.ask.com/question/define-transportation-corridor

According to the Transportation Research Board's (TRB) NCHRP 399, *Multimodal Corridor and Capacity Analysis Manual* (CSI et al, 1998):

"*The definition of a corridor encompasses a broad and loose meaning of the word. Indeed, there is no hard definition of the word. ….. Most corridors are identified by the primary facility or facilities that are included. For instance, portions of the interstate highway system,…*" (page 17).

TRB's more recent Guidebook for Corridor-Based Statewide Transportation Planning (Carr et al, 2010) also offers only broad insights into corridor study area definition. The principal intent of this guidebook is, rather, to describe a strategic approach for using the results of individual corridor plans in developing a full statewide transportation plan: assuming that practitioners already know how to carry out individual corridor studies. However, while no details are provided for constructing the most appropriate geographic study area boundaries in support of such studies, the report does provide lists of the criteria used in a number of State DOTs for its corridor selection purposes. In contrast, the guidelines offered by both Smith (1999) and Carr et al (2010) focus principally on the steps required of MPOs and State DOTs, to develop multi-agency and stakeholder relevant management plans; again with comparatively limited attention paid to the identification of an appropriate study area. That is, they focus on what Rodrigue et al (2013) term the formal aspects of corridor definition, as opposed to the function definition of a corridor as a geographic entity that captures those flows (of freight and/or passengers) whose movement volumes and spatial patterns collectively determine a study area's travel conditions both now and in the (planning context specific) future. The TRB funded Guidebook for Transportation Corridor Studies (Smith, 1999) offers the following definition:

"*Broadly defined, a corridor generally refers to a geographic area that accommodates travel or potential travel. Normally, a corridor is considered to be a 'travel shed,' an area where trips tend to cluster in a general linear pattern, with feeder routes linking to trunk lines that carry longer distance trips in a metropolitan area.*"

Smith (1999) also offers the following insight into study area definition (page 1-3):

"The exact extent of the corridor to be studied is best determined during the identification of the problem and determination of the corridor study strategy."

while noting that most practitioners, however they may disagree on specifics, would likely agree that:

- The study area needs to be large enough to incorporate all impacts relevant to the decision at hand; and

- Agencies should try to limit the study area as much as possible to focus the study and control the costs of analysis.

However, the specific details leading to selection of a study area corridor, not developed in detail as part of these guidelines, are then a function of the goals and scope of the study, both geographically and contextually.

In addressing this topic of corridor definition within the context of "integrated corridor management" (within metropolitan areas) Reiss et al (2006) provide numerous example definitions, eventually settling for their particular study purposes on:

"Corridor – A largely linear geographic band defined by existing and forecasted travel patterns involving both people and goods. The corridor serves a particular travel market or markets that are affected by similar transportation needs and mobility issues. The corridor includes various networks (e.g. limited access facility, surface arterial(s), transit, bicycle, pedestrian pathway, waterway) that provide similar or complementary transportation functions. Additionally, the corridor includes crossnetwork connections that permit the individual networks to be readily accessible from each other."

Finally, a recent paper by Bahbouh and Morency (2014), albeit with a focus on defining corridors within urban areas, tries to introduce a greater degree of formalism into corridor definition, basing its approach on the visualization and identification of corridors from origin-destination (O-D) data. In doing so, the authors note that "most research has used the corridor concept to recognize travel patterns with no clear definition of the *(corrido*r) concept." They distinguish between two different approaches to corridor definition in the past literature: supply corridors and demand corridors, with the latter usually based on O-D flow patterns. Focusing on demand-defined corridors, they use GIS technology to map an O-D flows matrix, with subsequent clustering to identify and map the main concentrations of flow. They suggest the use of i) a minimum flow density, ii) a suitable corridor width or zone of influence, and iii) a corridor minimum length, as three criteria for corridor definition.

As a practical matter, most U.S. based inter-city or inter-state freight corridor studies carried out over the past decade, including all of the above-referenced studies, make use of geographic information systems

(GIS) software in the corridor identification as well as display process. Many of these studies also make use of the federal government's Freight Analysis Framework (FAF) dataset; and notably its GIS-mappable, and highway network database-supplied nationwide truck trip assignment estimates and forecasts (FHWA, 2014) to identify high volume truck corridors of interest/concern.

Few regional features lend themselves more readily to mapping than linear corridors. Three example studies demonstrate the value of GIS technology to the corridor planning/selection process. One of these is the study by Alam and Fepke (1998) who modelled annual truck freight movements along the I-90/I-94 corridor between Seattle, WA and Chicago, IL. With the goal of understanding how these movements were influenced by truck size and weight (TS&W) regulations, the GIS software produced several useful corridor graphics, covering 9 States and showing, inter alia, parallel rail lines, the locations of commercial and population activity centers, metropolitan areas, and intermodal terminals (mainly rail-truck transfer facilities). The study also mapped estimated truck flows by vehicle class to Interstate sections, as well as state specific TS&W restrictions along the corridor. Using a field survey of some 7,700 trucks, this study also describes one of the earliest efforts to associate truck size and commodity-related body types with specific highway sections of an inter-city (and inter-state) corridor. Two, more recent example studies, carried out by Liao (2009) and Southworth and Gillett (2011) also used GIS software and FAF data to develop truck freight corridor performance measures. This last study was carried out for the rural portion of the I-75 corridor between Macon, GA and Valdosta, FL and integrates FAF network link flow and capacity data estimates with Georgia DOT-supplied traffic counts by truck size class, and GPS-based, hourly Interstate highway truck traffic speeds reported by the American Transportation Research Institute (ATRI).

In summary, and while the details leading to selection of a freight corridor study area are very much a function of a study's specific goals and scope, both geographically and contextually, these and other recent studies display at least five common elements:

1) a pattern and volumes of travel movements feeding into, through and out of a dominant linear transportation network infrastructure, such as a primary highway, major waterway, or major rail line, or an in-parallel combination of two or more of these mode specific features;
2) a common set of travel origins and destinations whose choice of routes (and possibly also modes) lead to significant levels of multi-origin, multi-destination traffic-related interaction;
3) the existence and/or expectation of high traffic volumes, and costly congestion induced travel delays along the corridor's primary network infrastructure (usually an interstate highway); and an assumption that financial economies of scale exist from these corridor-channeled traffic flows;
4) the use of existing, federal government supported datasets, and notably the FAF freight flow and highway network assignment dataset, and both State DOT and FHWA-supported and ATRI supplied truck count and GPS tracking data along the corridor's major facilities; and
5) the use of GIS software to support both the corridor visualization and corridor definition process.

In developing a national freight network to assist States in strategically directing resources for the improvement of freight movements on highways, the 2012 MAP-21 legislation included factors for the USDOT to consider in designating its primary freight network. These factors included: origins and destinations of freight movement; total freight tonnage and value moved; traffic volume; ports of entry; access to energy exploration, development, installation, or production areas; population centers; and network connectivity. Collectively, these criteria stated that a corridor could be designated if a minimum share of the annual average daily traffic on that route was attributed to trucks, and if the corridor provides connectivity between the primary freight network or Interstate System and facilities that handle heavy amounts of commodities on an annual basis.

Given the present study's focus on congestion-influenced freight value of time, it was also important to have access to data on (or, more precisely, to data that could be used to estimate) the origin-to-destination movements of specific classes of commodity within the corridor – for which the FAF (Version 3) data again provided a basis for model-based estimation.

2.3 Corridor Selection: The Interstate-85/285 Corridor in Georgia

Using the criteria listed above in Section 2.2, a truck freight corridor based on I-85/I-285 within Georgia was selected for case study. This corridor is approximately 178 miles long, running south-west to north-east between Troup and Hart Counties, and passing through the metropolitan area of Atlanta near its mid-point. The corridor currently exhibits a high level of daily truck traffic, which is expected to grow significantly over the next two to three decades. As illustrated by the latest ATRI rankings of the most congested portions of the nation's interstate system (Short and Murray, 2015) this corridor already experiences significant mixed auto-truck traffic congestion along many sections of its route, and notably where it intersects with other high volume interstates around Atlanta [6]. Such congestion is projected to grow much worse over the next two to three decades if current highway capacities and freight mode shares within the corridor's flow-influencing region remain unchanged. The principal source for this information was FHWA's Freight Analysis Framework, Version 3 (FAF3) dataset and supporting truck flow maps (FHWA, 2014). Figures 2.2, 2.3 and 2.4 map the corridor, showing respectively, how through trucks are routed around Atlanta via that metropolitan area's I-285 "perimeter" ring road (Figure 2.2), the FAF3 2007 estimate and 2040 forecast of annual average daily truck traffic (AADTT) volumes on I-85 and the other interstate corridors within Georgia (Figure 2.3), and the location of the corridor with respect to flows from and to origin-destination (O-D) pairs of places in other states that appear to have resulted in some truck traffic on the study corridor in 2007 (Figure 2.4).

Based on FAF3 forecasts, truck tons and ton-miles of freight either generated or received within a six state region that includes Alabama, Florida, Georgia, South and North Carolina and Tennessee are

[6] The I-85N/I-285 interchange was ranked as the most congested location for trucks on the Interstate system in this American Transportation Research Institute (ATRI) report, based on GPS reported truck speeds from around the nation.

projected to increase by more than 45% and 68% respectively over the 25 year period between 2015 and 2040: *while the monetary value of this freight increases by almost 93%*. This includes significant anticipated traffic growth over the next two and a half decades along much of the I-85/I-285 corridor within Georgia, on the order of 97% growth in average annual daily traffic (AADT) of all vehicle classes between 2007 and 2040, and with truck AADT growing by as much as 71% on I-85 and 75% on I-285 during this period (see Figure 2.5). Such traffic growth would produce unsupportable volume-to-capacity (v/c) ratio increases along the corridor at its current throughput capacity and with no shifts to alternative modes of transportation (see Figure 2.6), with many highway sections experiencing average space mean speed reductions of greater than 40% well before 2040. Such estimates illustrative of the size of the infrastructure investment problem transportation planners and decision-makers will need to face up to if freight demand continues to rise at anything like the pace it has demonstrated over the past four decades.

2.4 On the Use of 2007 Data

The present study makes use of 2007 data. The main reason for this was a desire to test the multi-step modeling procedure on established data sets, notably the availability of the FAF3 dataset on inter-regional, multi-modal and multi-commodity flows. (The recently released, 2012-model year based FAF4 dataset was not yet available). Also, while a number of statewide and metropolitan freight data collection efforts and studies have been carried out by the Georgia DOT and Atlanta Regional Commission (ARC, the region's MPO), the focus of the current research effort is on methodology development and testing, with the potential for use on more recent datasets seen as a future possibility –and perhaps an opportunity for a time-lapsed comparison.

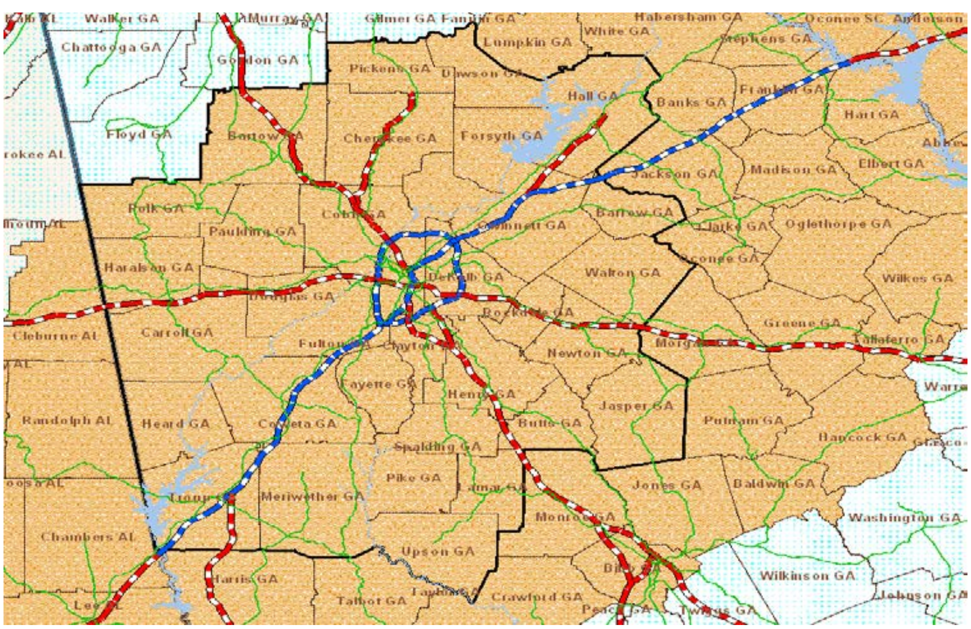


Figure 2.2 The I-85 Study Corridor in Georgia

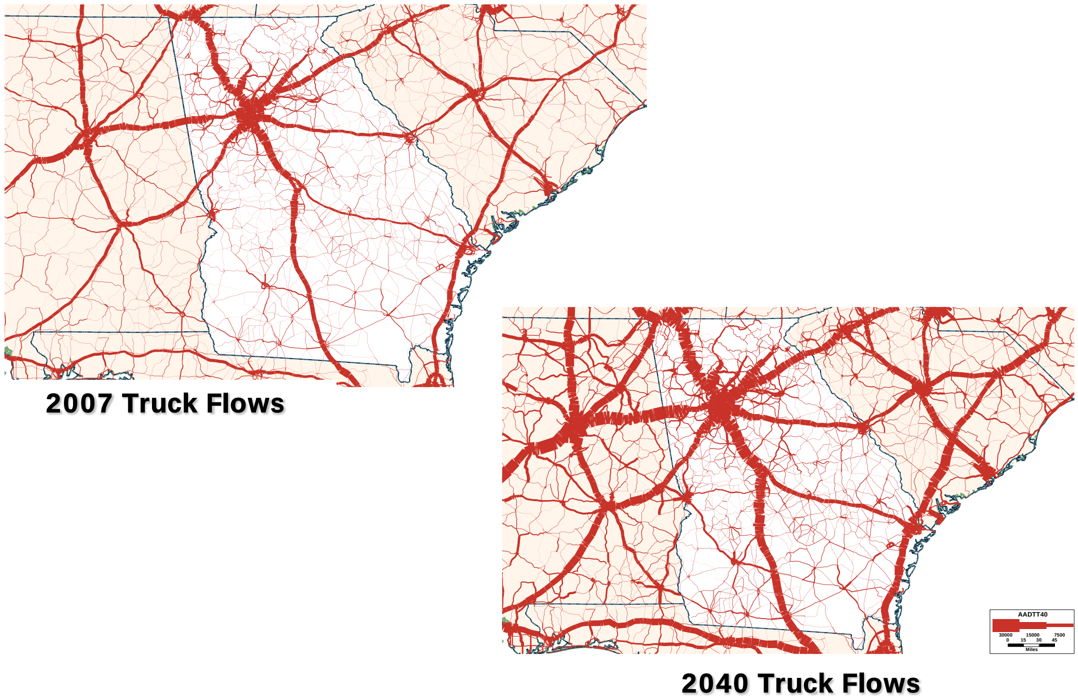
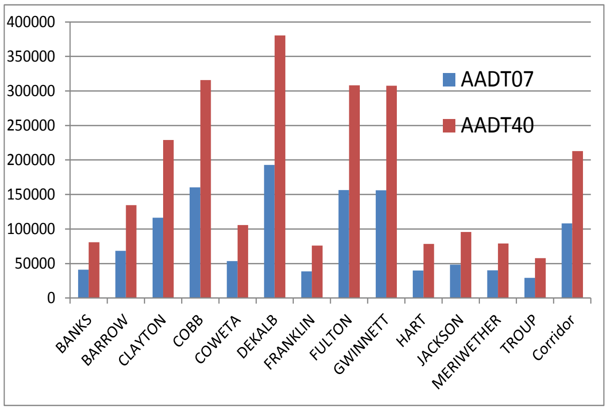


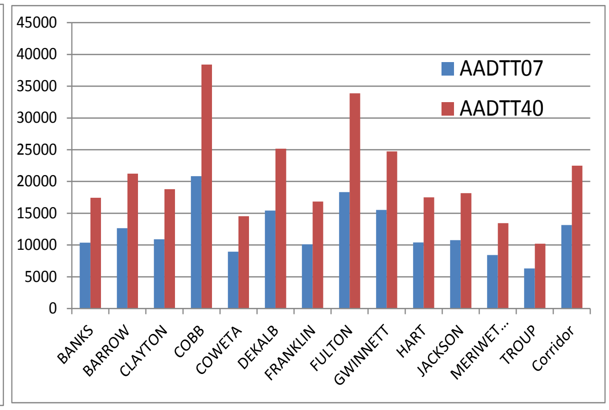
Figure 2.3 FAF3 AADTT Estimates for 2007 and 2040: Georgia Corridors

Figure 2.4 Truck Flows between O-D Pairs that influenced I-85 Corridor Traffic in 2007
(estimated, based on FAF3 and other data sources)

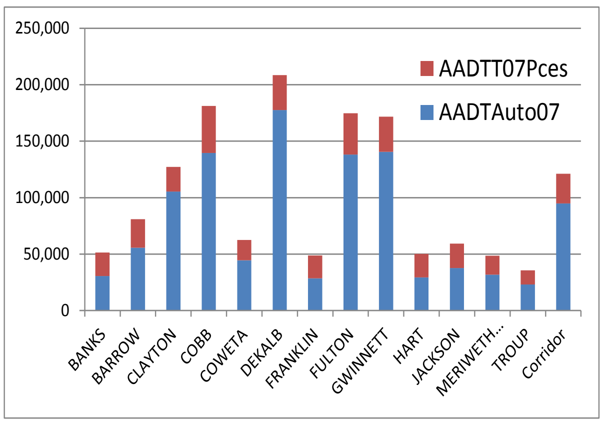
(A) AADT Traffic Volumes by County



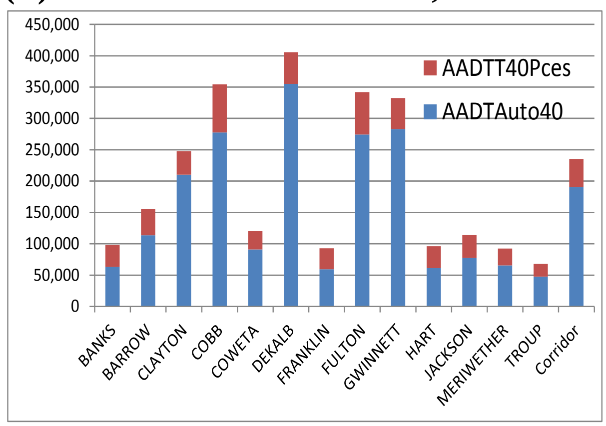
(B) Truck Traffic AADT Volumes by County



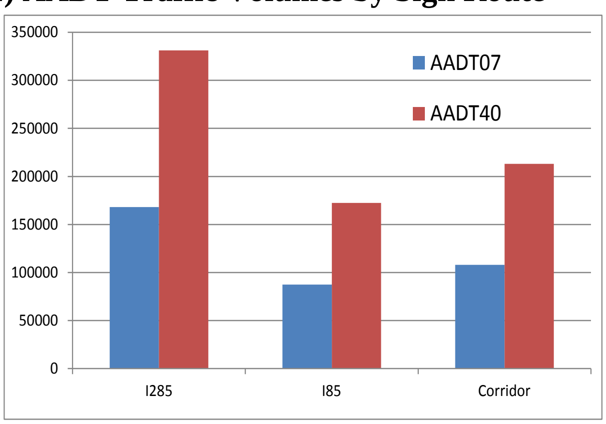
(C) Auto + Truck Traffic PCEs, 2007



(D) Auto + Truck Traffic PCEs, 2040



(E) AADT Traffic Volumes by Sign Route



(F) Truck AADT Volumes by Sign Route

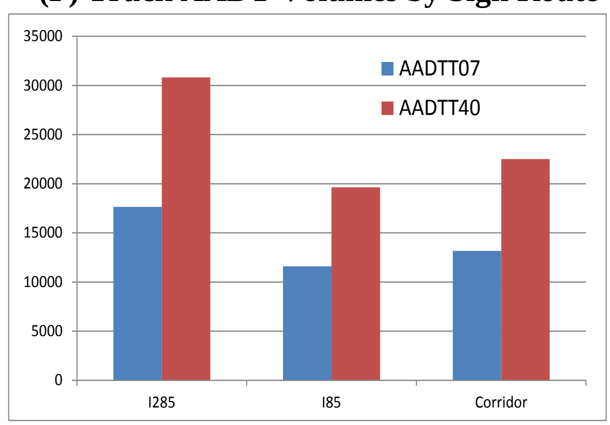


Figure 2.5 Three Views of Recent and Forecast Traffic Volumes on the I-85 /I-285 Corridor in Georgia (based on FAF3 data; see FHWA, 2014)[7]

[7] County AADTs and AADTTs in Figure 2.5 are link mileage weighted volumes aggregated to county averages for the 13 Georgia counties through which the corridor passes. PCEs are also link mileage averaged with 1 truck averaging 2 automobile PCEs corridor-wide in Figures 2.5C and 2.5D.

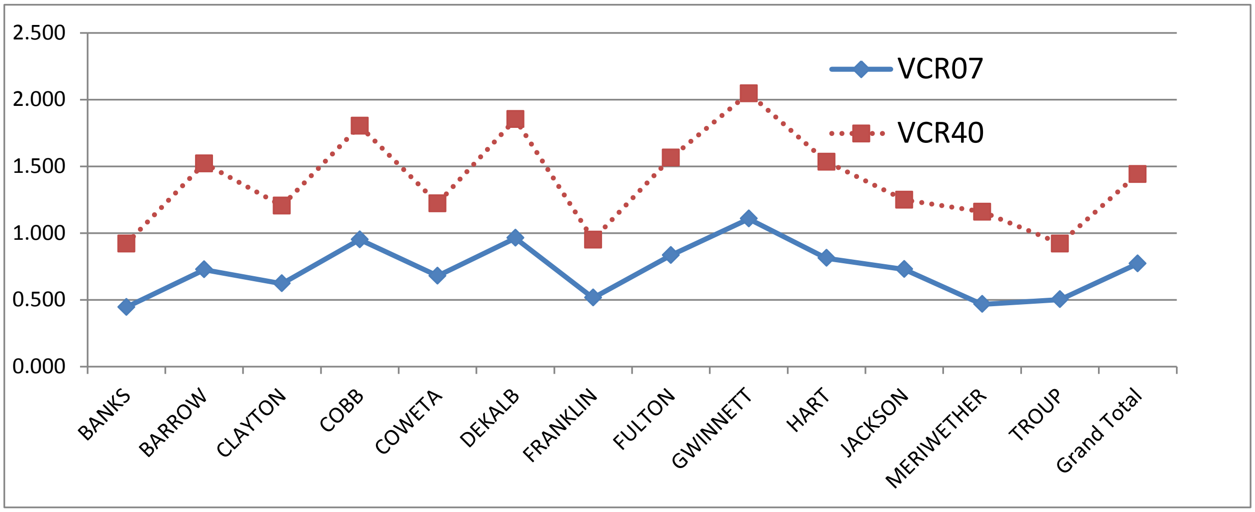


Figure 2.6 2007 and 2040 Volume/Capacity Ratios (VCRs) along I-85/I-285, by County
(Source: Derived from FAF3 estimates).

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Chapter 3. Candidate Corridor Users: Origin-Destination Flow Matrix Generation

3.1 Introduction

This chapter describes the process of constructing a set of daily and peak-hour truck traffic flows for the I-85/I-285 corridor as it passes through the state of Georgia. These traffic flows are disaggregated by truck size class, based on a procedure that estimates and allocates commodity class specific origin-to-destination trade flows on the basis of converting dollar values of economic activity, first into tons of freight transported, then into the number of truck trips of various size classes and body types needed to move these tons over the highway system. The ability to estimate the value of goods moved by truck on a route or corridor specific basis has emerged in recent years as a good candidate for measuring highway network performance (see Eisele et al, 2012, 2013 for example). The technical challenge involved creating a set of truck based commodity flow matrices at a level of spatial disaggregation suitable for corridor planning purposes, including the ability to subsequently assign such flows to a state's highway network (see Chapter 4) while using commonly available datasets.

The need to "model" existing freight movement data stems from the limited amount of spatially detailed commodity or truck flow data available, below the very broad regional level once an analysis moves beyond a single metropolitan area. A recent review of past efforts to create, and also forecast, spatially detailed truck-based commodity flow matrices by Southworth (2014) identified a number of different approaches to the problem, depending on both study purpose and resources. The 26 studies listed in that report run the gamut from simple factoring of regional commodity production, consumption, or production-consumption totals on the basis of industrial sector employment and population, to various types of regression analysis, structural equations modeling, or the use of inter-industry input-output tables linked to spatial interaction models that associate one industry's production or consumption, initially in dollar terms, with the inputs and outputs of other industries within or outside a region. None of these approaches proves to be entirely satisfactory, and a highly data intensive line of development is sometimes required to construct freight movements for specific commodity classes (notably agricultural and energy commodities) that offer more direct data sources. Within the United States each of these modeling options usually involves adjusting the resulting origination-to-destination commodity flow ("O-D-C") totals to fit those reported by the Federal Highway Administration's (FHWA) Freight Analysis Framework (FAF) data and modeling program (FHWA, 2014). Most of these modeling exercises have two major steps: 1) estimate the volume of freight a) produced and b) consumed within a region (e.g. a county), and 2) estimate the flows between all pairs of regions. In transportation planning terminology, this refers to trip generation and attraction modeling, followed by trip distribution modeling. In all cases, the result is a *synthetic matrix* of county or sub-county based origin-destination-commodity flows, usually for a given calendar year. These commodity flows are then converted to truck trips based on data sources that tie specific types and sizes of trucks and their average cargo load factors to specific commodity or industry classes.

A number of different trip generation and attraction modeling approaches were tested and compared, including the use of simple employment and population weighted freight activity totals, the use of literature-supported regression analyses, and the development of an input-output based disaggregation of county O-D flows. These approaches often produced significantly different results when converted into the corridor's subsequent truck trip based network assignments. Given this, and the lack of a strong theoretical preference for selecting between these approaches, a method was adopted that mirrors to a large degree that used to develop the original FAF3 O-D commodity flow matrices: making use of a popular supply side input-output approach to linking commodities produced in one set of industries to those consumed in down-stream product manufacture (see Southworth et al, 2011). The rest of this chapter describes this method, as it was used to construct a set of county (and sub-county) level commodity flow matrices, and their subsequent conversion to truck trips.

Table 3.1 FAF3 2-Digit SCTG* Commodity Classes

SCTG	Commodity	SCTG	Commodity	SCTG	Commodity
01	Live animals/fish	**15**	Coal	**29**	Printed products
02	Cereal grains	**16**	Crude petroleum	**30**	Textiles/leather
03	Other agricultural products.	**17**	Gasoline	**31**	Nonmetal mineral products
04	Animal feed	**18**	Fuel oils	**32**	Base metals
05	Meat/seafood	**19**	Natural gas and petroleum prods.	**33**	Articles-base metal
06	Milled grain prods.	**20**	Basic chemicals	**34**	Machinery
07	Other foodstuffs	**21**	Pharmaceuticals	**35**	Electronics
08	Alcoholic beverages	**22**	Fertilizers	**36**	Motorized vehicles
09	Tobacco prods.	**23**	Chemical prods.	**37**	Transport equipment
10	Building stone	**24**	Plastics/rubber	**38**	Precision instruments
11	Natural sands	**25**	Logs	**39**	Furniture
12	Gravel		Wood products	**40**	Misc. mfg. products.
13	Nonmetallic minerals	**27**	Newsprint/paper	**41**	Waste/scrap
14	Metallic ores		Paper articles	**43**	Mixed freight
				99	Commodity unknown

* Standard Classification of Transported Goods

The commodity classes used are the 43 classes defined by the 2007 U.S. Commodity Flow Survey and its expanded coverage to non-CFS surveyed industries, as captured by 2007 FAF3 dataset. See Table 3.1. These truck trip matrices are then further disaggregated according to five truck size classes (see below) for use in the travel cost and subsequent network traffic assignment modeling steps.

3.2 Study Corridor Definition

Figure 3.1 shows the study corridor in its national context. Truck flows within and through the corridor were modeled using a three-tier spatial disaggregation process.

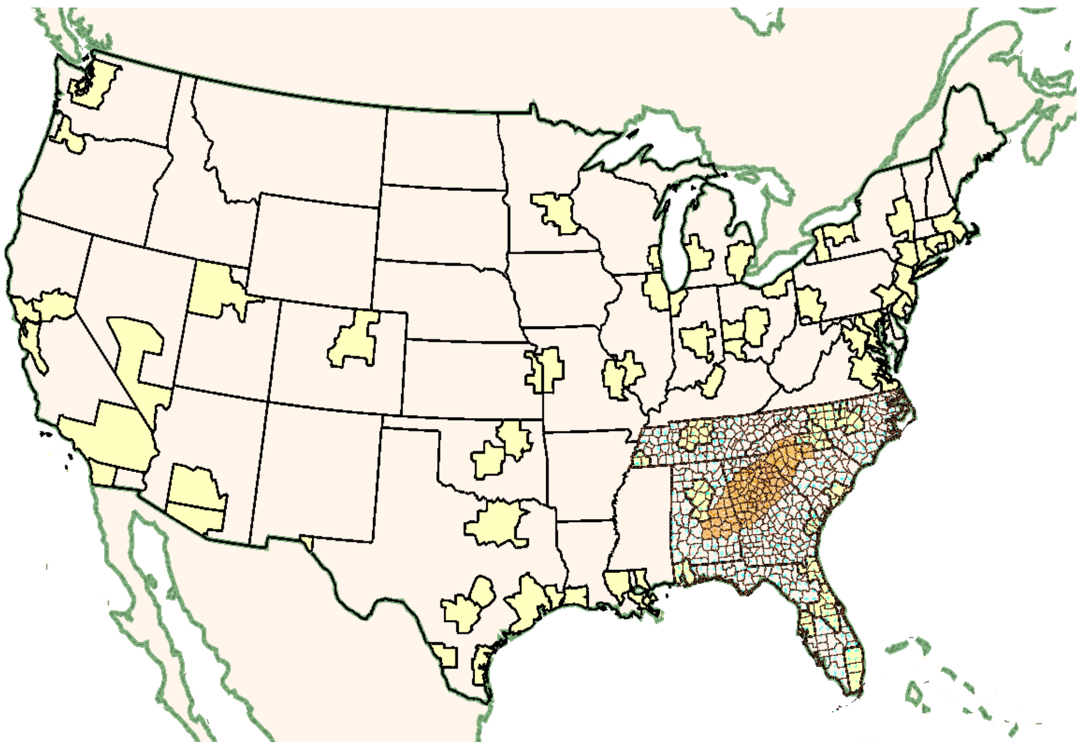

Figure 3.1 Corridor Study Area, National Context: Tier 1 and 2 Traffic Analysis Regions

Tier 1 provides nationwide coverage (including import and export flows through the nation's ports and border crossings) and is represented by the 123 internal to the U.S. FAF3 regions or regional analysis zones. These include 74 metropolitan area regions (shown in yellow in Figure 3.1), 33 regions made up of state remainders which represent a state's territory outside these metropolitan regions, and 16 regions identified as entire states within which no FAF3 metropolitan regions exist (Southworth et al, 2011).

Based on a study of FAF3 inter-regional truck freight movement data, a six state region surrounding the corridor was selected for Tier 2, county level disaggregation. Figure 3.2 shows this six state south-eastern region (i.e. Alabama, Florida, Georgia, North and South Carolina and Tennessee), showing the region's counties and also its interstate highway system. This south-eastern region contains twenty-one FAF3 analysis zones, including fifteen FAF3 metropolitan regions and six state remainders, containing a total of 534 south-eastern region counties.

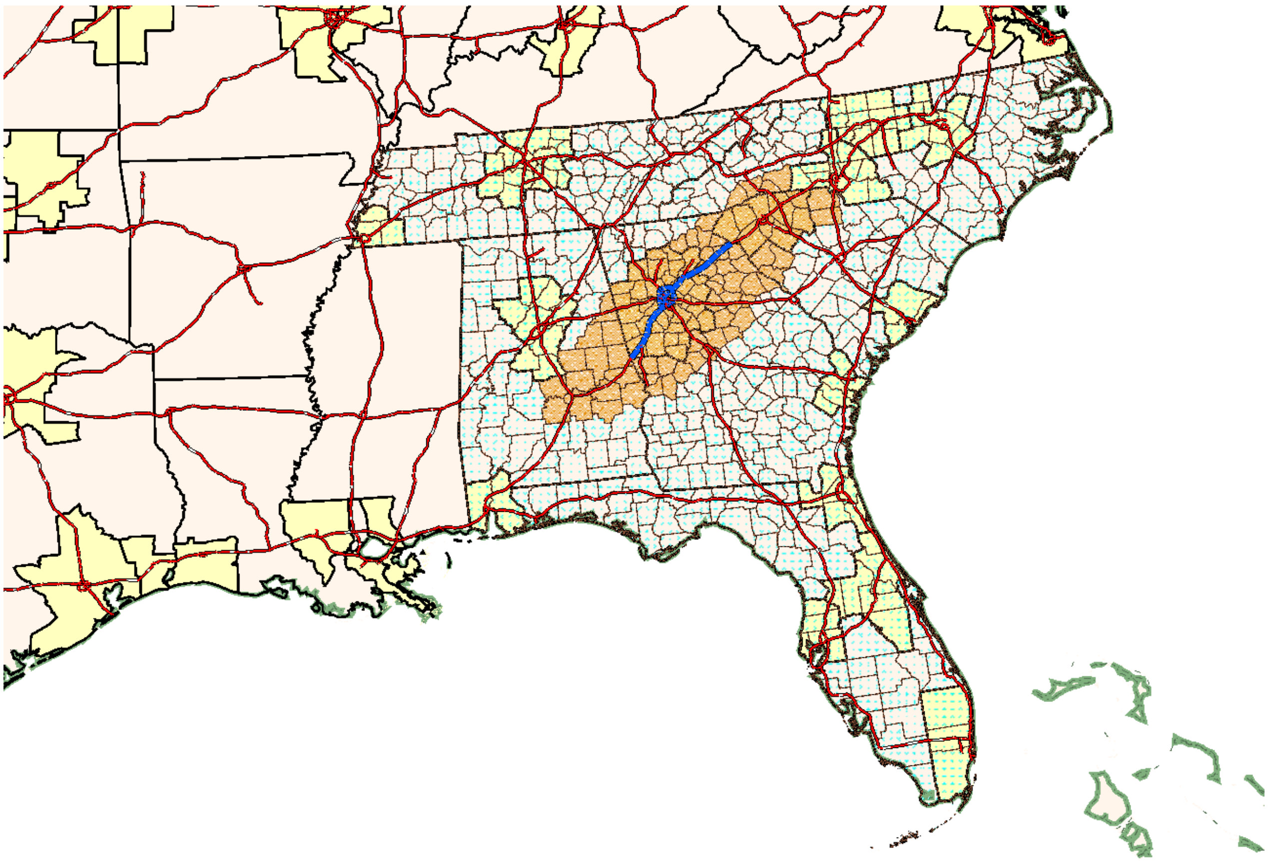

Figure 3.2 The Six State Southeastern Region's Counties and Interstate Highways

3.3 Defining Internal and External Trips: Tier 1 Disaggregation

Commodity flow origins and destinations outside the corridor's six state southeastern region are based on FAF3 regions and termed external trip ends, with trips that both begin and end outside this region termed external-external (E-E) flows (of which there are a potential 102 x 102 flows for each commodity class). These flows are not disaggregated and remain entirely Tier 1 flows. Commodity flows that start outside the region and end up within one of the 534 counties internal to the region are termed external-internal (E-I) flows, and those flows that begin within the region and end up outside it are termed internal-external (I-E) flows. There are therefore potentially 102*534 and 534*102 E-I and I-E flows respectively, for each commodity transported. These two flow sets combine Tier 1 and Tier 2 levels of spatial (dis)aggregation. Finally, there are a potential 534 x 534 internal-internal (I-I) inter-county Tier 2 level flows, resulting in a rather sparse (i.e. lots of zero valued cells) matrix. This was the level of disaggregation that was used to identify the most important O-D flow pairs using the corridor, including those diads that might benefit from further spatial disaggregation.

3.4 Tier 2 (County Level) Disaggregation Method

A number of different spatial disaggregation methods were experimented with in order to assign FAF3 O-D-Commodity flow totals to within-region county pairs. A two-step process was followed. Step 1 involved the estimation of county level commodity productions (= originations, or Os) and attractions (= destinations, or Ds). Step 2 then estimates the flows between these O-D pairs of counties.

3.4.1 County Level Production (Supply)

Industries Covered by the U.S. Commodity Flow Surveys

The majority of commodity production estimates were derived using US Commodity Flow Survey (CFS) tables. These tables cross-tabulate the 43 SCTG commodities shown in Table 3.1 above against the industrial sector breakdowns used by the North American Industry Classification System (NAICS). That is, these NAICS industries are the ones producing the SCTG-classified commodity flows reported by the CFS. In particular, Table 12[8] provides 2007 estimates of shipped tons, dollar trades, and ton-miles transported by CFS (also = FAF3) freight generation regions, cross-classified by 2-digit SCTG and from 2-to-6-digit NAICS codes, depending on specific commodity class. Using this data, FAF3 truck freight productions (in tons) was shared across each FAF region's counties using U.S. Census reported County Business Patterns (CBP) data on annual employment and payroll dollars in each NAICS-specific industry (U.S. Census Bureau, 2014), i.e.

$$T(i,C) = \sum_{g \varepsilon G(C)} T(I,C,g) * [\, E(i,g) / \sum_{i \varepsilon I} E(i,g) \,] \qquad (3.1)$$

where T(i,C) = estimated tons of commodity C originating in county i.
T(I,C,g) = annual tons of commodity C shipped out of CFS (= FAF3) region I by industry g; E(i,g) = total annual employment or payroll dollars associated with industry g in county i.

This approach, however, does not work for industries not included in the shipper establishment-based CFS (and referred to in the FAF3 documentation as "out-of-scope", or OOS industries: See Southworth et al, 2012). This includes farm-based and utility-based commodity flows, while the CBP dataset also excludes NAICS industries involved in crop and animal production. Equation (3.1) is also not a reliable method for estimating some energy commodities, notably coal shipments, whose freight tonnages are not

8 http://apps.bts.gov/publications/commodity_flow_survey/2007/metropolitan_areas/remainder_of_hawaii/html/table_12.html

easily tied to employment or payroll totals, and which are usually associated with a limited number of (fortunately well documented) coal mining and electric utility sites. This led to the following approaches to disaggregating these various commodity classes.

FAF3 Out of Scope Industries

The following industries were not part of the 2007 CFS, and therefore required an appropriate allocation to their respective SCTG commodity classes prior to disaggregating FAF3 regional commodity production totals:

1. Farm Based
2. Fishery
3. Logging
4. Construction
5. Services
6. Retail
7. Household and Business Moves
8. Municipal Solid Waste
9. Crude Petroleum
10. Natural Gas Products

For spatial disaggregation purposes these industries are largely one commodity based, and if captured by the CBP data are therefore easily distributed across counties: or they produce commodities that span more than one 2-digit SCTG class, and therefore require a sharing of their output across these commodities. The following paragraphs describe how each industry was treated in this present study.

Farm-Based Agricultural Commodities and Fisheries

Farm-based agricultural commodity flows are not reported by either the CFS or CBP datasets. Spatial disaggregation was accomplished using county-level farm production data from the 2007 Census of Agriculture, with data drawn from USDA's Desktop Query Tool version 1.2 (USDA, 2009). This production data is reported as number of animals sold and either crop sales or crop acres harvested. This data was then converted (e.g. from bushels, bales, weight per animal) to kilotons, using the per unit weight conversions for specific crops and types of livestock published by the USDA (see USDA 1992).[9] Livestock sales within a county (composed of cattle and calves, broiler and other meat-type chickens, layers, pullets and eggs, turkeys, pigs and piglets, sheep and lambs, goats, and horses and ponies sold) were derived and assigned to SCTG1, while grain crops (including barley, corn, oats, rice, rye, sorghum and wheat) were assigned to SCTG2 and vegetables, fruits and nuts and other farm crops, including beans, cotton, peanuts, soybeans, sugar cane, sugar beets, and tobacco, were assigned to SCTG3. Raw

[9] In some cases a direct conversion to commodity specific tons was not readily available. For example, milk production was estimated as the number of milk cows in a county multiplied by the average milk yield per cow for that state. The tons of fruits and nuts shipped was based on a county's farm acreage in citrus fruit, non-citrus fruit, and nuts multiplied by the average yield per acre for each of these three commodity sub-classes.

milk production was assigned to SCTG4. Fish are reported under NAICS category 114 (fishing, hunting and trapping) in the CBP.

Construction, Household and Business Moves, Retail, and Service Industry Commodities

Commodities produced by industries in NAICS categories 23 (Construction), 44 (Retail), 52 (Services) and 4842 (Specialized Freight Trucking) were distributed on the basis of BEA's 2007 industry–to-commodity make tables. Figure 3.3 below (taken from Southworth et al, 2011) shows the principle NAICS to SCTG relationships involved.

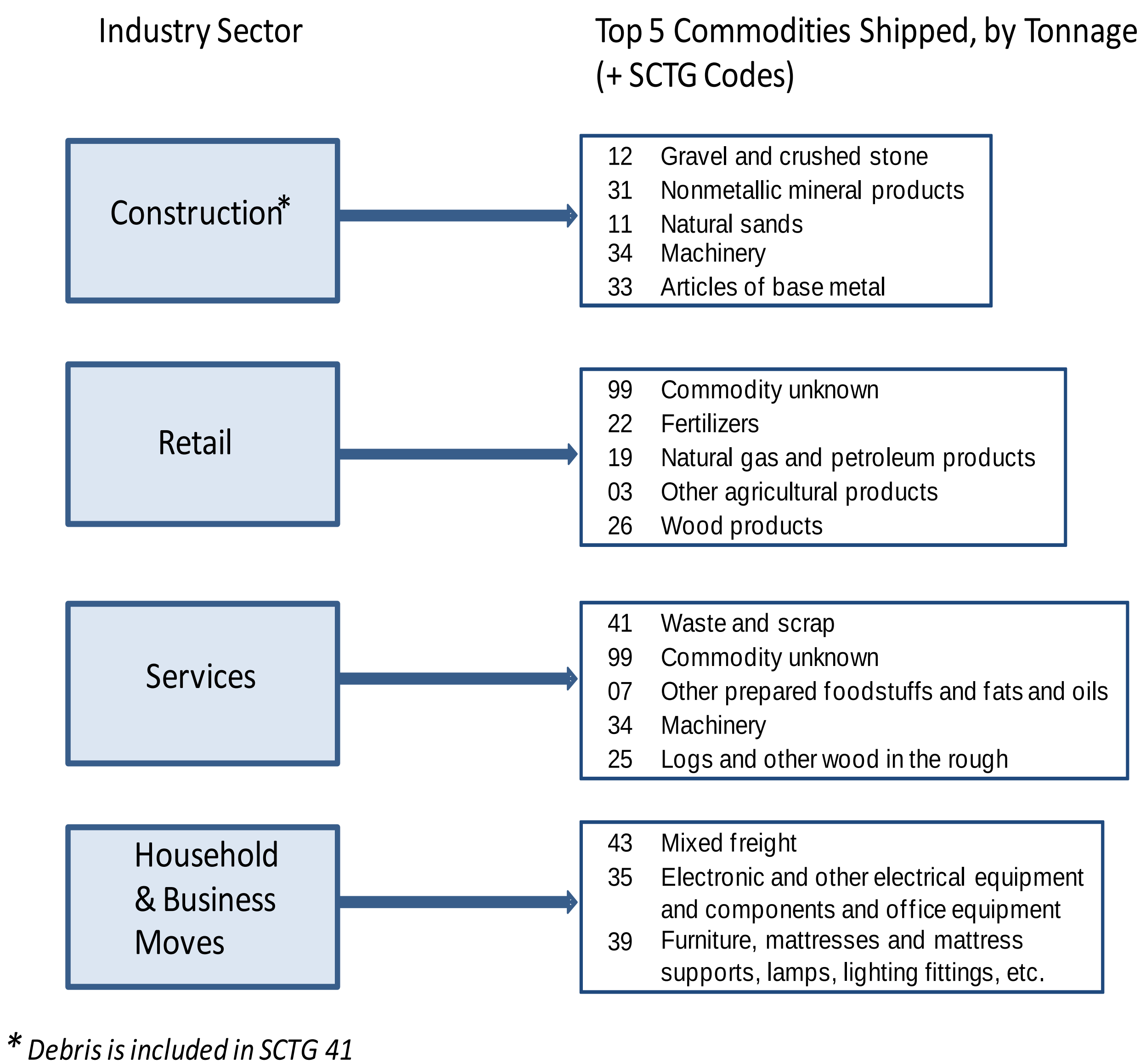

Figure 3.3 Principal Commodities Shipped by Tonnage in Four Industrial Sectors

Logging products (SCTG 25) were allocated on the basis of county employment activity in NAICS category 113.

Municipal Solid Waste

Municipal Solid Waste (MSW)[10] presents something of unique challenge. It does not have a specific code in NAICS. Its production was shared to counties on the basis of a county's employment in durable and non-durable goods, construction, retail and service industries, making use of the allocations to waste and scrap derived for each of these other industry classes.

Crude Petroleum and Natural Gas

County allocations of FAF3 regional production totals were based on employment in NAICS class 211111 – 'Crude Petroleum and Natural Gas Extraction.'

Coal

The amount of coal mined and shipped does not correlate well with either employment or payroll data, and its spatial disaggregation was therefore treated separately. There was a limited amount of coal production in the six state south-eastern region in 2007, most of it concentrated in just 10 Alabama and 3 Tennessee counties. Fortunately also, data sources on the coal industry are among the best reported commodities. Annual coal plant production data for these counties, reported in kilotons, was created from individual coal plant data reported by the Energy Information Administration (EIA, 2014). To this data were added FAF3 seaport region-specific imports, extracting only those moved inland by truck. Over 94% of these within- region shipments came in through the five ports Charleston SC, Jacksonville and Tampa FL, Mobile AL, Savannah GA, with a small volume also entering through the port district covering the Remainder of North Carolina: a result found to be consistent with the EIA's 'Monthly Report IM 145' data series for 2007. This combined production and import data was then used to share internal coal originating shipment volumes across study area counties in a manner that matched the volumes reported by FAF3 truck shipments

3.4.2 County Level Freight Consumption (Demand)

County specific freight attractions pose a more difficult problem than productions, largely because the CFS is a shipper-at-origin based survey, and because the number of either raw or intermediate product inputs into many industrial processes is often larger than the number of products coming out of a particular industry. This is where an input-output (I-O) based approach offers the considerable advantage of being able to link such, often diverse, commodity inputs to industry outputs. This includes the assignment of final product sales (and hence trades) to U.S. households, government agencies, and

[10]MSW includes: containers and packaging, such as soft drink bottles and cardboard boxes; durable goods, such as furniture and appliances; nondurable goods, such as newspapers, trash bags, and clothing; and other wastes, such as food scraps and yard trimmings.

foreign exports (see Miller and Blair, 2009, for example). County and commodity class-specific shipment destinations were estimated in this project using the Bureau of Economic Analysis' (BEA) 2007 national commodity-to-industry "Use" table to first of all associate specific commodity classes with the industries that make use of (i.e. that purchase) them. Specifically, if we let V(C,g) refer to the dollar value of commodity C used in industry g, then:

$$U(C,g) = V(C,g)/\Sigma_C V(C,g) \qquad (3.2)$$

which equals the share of commodity C used in the total ($ valued) output of industry g. With this we then compute:

$$T(C,j) = T(C,J) * \{\sum_{g\varepsilon G(C)} U(C,g) * [\, E(j,g) / \sum_{j\varepsilon J} E(j,g)\,]\} \qquad (3.3)$$

where T(C,j), T(C,J) = the tons of commodity C destined for county j and for FAF region J, respectively, E(j,g) = the annual employment in industry g in county j receiving commodity C; and the summation in equation (3.3) is over all industries that consume commodity C.

In words, and working backwards from right to left, equation (3.3) combines two share computations, one spatial and the other industry sector-based. First it computes the share of industry g's activity, represented by its employment, found in county j. Then it multiplies this share by the share of commodity C produced by industry g, repeated and summed over all g=1,2,..G industries that use commodity C in county j. Finally, this result is then factored to sum to the volume (tons) of C delivered to FAF3 region J by truck.

The major drawbacks of this and other, similar I-O approaches are due to a) the limited spatial disaggregation in current I-O tables (which average over some potentially significant regional differences in product composition and productivity in some cases) and the rather crude breakdown of "commodities" within the national I-O accounts, with limited detail available within many industrial sectors. For forecasting purposes, the essentially static nature of the I-O tables also represents a third limitation. This said, the approach has seen a good deal of use for freight flow modeling over the past two decades, both within the U.S. and abroad, because of its ability to tie the supply side of commodity flows to the demands for goods as both intermediate and final products within industry supply chains.

Note that this dollar based commodity-to-industry translation can be turned back into both commodity-specific dollars and also into tons shipped using CFS average $/ton statistics, while annual payroll dollars spent in industry g in each county can also be used to share the commodities involved across counties. Note also that by using the FAF truck specific volumes T(C,J) in equation (3.3) there is an implicit assumption that all counties get a share of this trucking activity irrespective of whether or not they may contain a rail or water option to move certain commodities that ought to limit their use of truck. This result can then be adjusted where a specific county is known to contain one or more significant rail or water terminals or transfer facilities that would typically process a specific commodity. The use table employed in this disaggregation was the six-digit NAICS-based “IOUse_After_Redefinitions_2007 Producer Value” table, drawn from the 2007 benchmark national Input-Output accounts released on December 18, 2013 (BEA, 2014). This table allowed re-aggregations of 377 detailed NAICS industrial classes into the 43, 2-digit SCTG commodity classes used in the freight flow modeling.

Coal

To obtain the likely destination county for coal shipments, a surrogate for annual coal delivery data was obtained from the Environmental Protection Agency’s (EPA) eGrid website, in the form of utility plant-specific and coal-based net electricity generation, reported in megawatt-hours, or MWh (EPA, 2014). According to FAF3, coal exports resulting from truck trips into a port county were limited in 2007, principally through Mobile AL, with a small volume also passing through Miami FL. FAF3 regional coal truck freight destination totals were then shared to these utility plant-located counties using the MWh data, again rectified to match FAF3 intra-regional truck destination totals. The most likely error introduced by this method is the assumption that truck mode shares are similar across within-region counties.

3.4.3 Inter-County (O-D) Commodity Flows

The simplest method for creating a set of inter-zonal flows, given a set of county specific Os and Ds, is to share these flows between all zones within each pair of FAF O-D regions. This is done on the basis of the relative cross-product of each county’s O and D volumes, with the results then reconciled back to the FAF region-to-region O-D flow totals, i.e. for each commodity, C in turn, we compute:

$$T(i,j) = FAF(I,J) * [\ O(i) / OFAF(i) \quad * \quad D(j) / DFAF(j)] \tag{3.4}$$

where T(i,j) = the annual tons of the commodity moving between counties i and j; O(i) = county i production (originations), D(j) = county j attraction (destinations), and OFAF(i) and DFAF(j) = the county aggregated FAF3 regional activity totals for the commodity being flowed, computed as:

$$OFAF(i) = \sum_{i \varepsilon I} O(i) \qquad \text{and} \qquad DFAF(j) = \sum_{j \varepsilon J} D(j) \tag{3.5}$$

This approach was applied to the E-I and I-E flows that move freight into and out of Georgia respectively. It allows full advantage to be taken of the FAF3 inter-regional O-D flows as suitable control totals. It does not, however, recognize the potential effects of additional, notably distance-based transportation costs on these interaction patterns. This effect is usually captured by a series of *commodity specific* spatial interaction (SIA) or “gravity” models. This was the second approach used, applying the following general SIA formula to each commodity in turn:

$$T(i,j) = O(i) * D(j) * G[Cost(i,j)] * A(i) * B(j) \tag{3.6}$$

where the A(i) and B(j) terms are the usual iteratively derived balancing factors used in doubly constrained spatial interaction models (Wilson, 1970)[11]; where G[Cost(i,j)] = a trip distance influenced cost-decay function. Two different functional forms were experimented with:

$$\text{Cost}(i,j) = \alpha 1 * \text{Money}(i,j) + \alpha 2 * \text{Travel Time}(i,j) + \alpha 3 * \text{Travel Time Reliability}(i,j) \quad (3.7a)$$

and

$$\text{Cost}(i,j) = \alpha 1 * \text{Money}(i,j) + \alpha 4 * \text{Travel Time Reliability}(i,j) \quad (3.7b)$$

for a set of model cost sensitivity parameters α1 – α4, and where "Money" cost in equations (3.7a and 3.7b) is broken down as follows (see, for example, Torrey and Murray, 2015):

$$\text{Money}(i,j) = \text{Labor Costs}(i,j) + \text{Fuel Costs}(i,j) + \text{Other Vehicle O\&M Costs}(i,j) \quad (3.8)$$

where labor costs are mainly hourly estimated driver wages, and fuel costs and O&M costs refers to the marginal (per mile or per hour) costs of vehicle operation and maintenance, with O&M costs including vehicle repair, maintenance and insurance costs, lease or purchase payments, permits and licenses (no tolls involved). This method was used to calibrate a set of 43 commodity specific interaction models for flows occurring between all county pairs within the six state south-eastern region.

TransCAD's gravity application was used to distribute tons of commodities between O-D pairs. To apply the gravity model, three pieces of data were needed: 1) the number of tons produced by each county, 2) the number of tons attracted to each county, and 3) the impedance between each county. Since only trip distance data was available for each commodity class, a set of distance based impedance functions was used to calibrate 43 commodity flow models that were then linked to the GIS software environment. To accomplish this the congestion-sensitive generalized trip cost formula defined by equation (3.8) was used with equations (3.7a) or 3.7(b) above, to distribute flows between O-D pairs, while fitting these flows to a set of truck average trip distance (per ton) statistics based on FAF3 reporting. After some experimentation, this approach settled, for further model testing purposes, on a set of inverse power functions of the form:

$$f[distance(i,j)] = distance(i,j)^{-\beta}, \beta > 0 \quad (3.9)$$

where the sensitivity to extra trip distance parameter, β, was allowed to vary until the resulting commodity flows produced an average trip distance equal or very close to that reported by FAF3. The resulting set of commodity-class specific beta (β) values are listed in Table 3.2. Of particular interest to

[11] i.e. $A(i) = 1/\sum_j B(j).D(j).G[Cost(i,j)]$ for all i; and $B(j) = 1/\sum_i A(i)O(i).G[Cost(i,j)]$ for all j.

the present study are the travel time and travel time reliability components referred to in equations (3.7a and b). While measurement of travel time is relatively straight-forward, measuring travel time (un)reliability is more challenging, but usually involves some assessment of the day-to-day variability in journey times over a suitable period (such as over a travel season, or a typical weekday). The α2 and α3 parameters in equation (3.7a) represent the importance placed on these value of travel time and value of travel time unreliability terms and offer a means of quantifying the costs of, respectively, additional travel time and travel time disruption. Equation (3.7b) drops the travel time component of travel cost but retains the time reliability component. The rationale for this is the inclusion of significant time-based costs within the Money costs, notably the hourly wages paid to the truck driver, as well as the impact of travel speed, and hence time, on the fuel consumed. This measurement issue is addressed further in Chapter 5 below.

Table 3.2 Commodity Specific (Distance Based) Generalized Cost Modeling Parameters

Commodity	Beta	Commodity	Beta	Commodity	Beta Value
01 Live animals/fish	2.634	15 Coal	1.568	29 Printed prods.	1.337
02 Cereal grains	2.423	16 Crude petroleum	1.204	30 Textiles/leather	1.124
03 Other ag. prods	1.446	17 Gasoline	2.736	31 Nonmetal min. prods.	2.868
04 Animal feed	2.093	18 Fuel oils	3.251	32 Base metals	1.819
05 Meat/seafood	1.369	19 Coal-n.e.c.	3.179	33 Articles-base metal	1.762
06 Milled grain prods.	1.424	20 Basic chemicals	1.721	34 Machinery	1.920
07 Other food stuffs	1.379	21 Pharmaceuticals	1.329	35 Electronics	1.341
08 Alcoholic beverages	1.657	22 Fertilizers	1.626	36 Motorized vehicles	1.499
09 Tobacco prods.	1.339	23 Chemical prods	1.405	37 Transport equip.	1.282
10 Building stone	1.819	24 Plastics/rubbers	1.131	38 Precision instruments	1.281
11 Natural sands	3.790	25 Logs	3.716	39 Furniture	1.258
12 Gravel	5.313	26 Wood prods.	2.288	40 Misc. mfg. prods.	1.250
13 Nonmetallic minerals	2.100	27 Newsprint/paper	1.518	41 Waste scrap	1.420
14 Metallic ores	1.698	28 Paper articles	1.427	43 Mixed freight	2.661
				99 Unknown	1.955

3.4.4 Tier 3 (Within County) Disaggregation Method

A Tier 3 disaggregation involving a breakdown of flows within selected counties adjacent to the I-85/I-285 highway (counties represented by the brown shading in Figure 3.2) was also developed, to allocate corridor flows to interstate corridor links where additional spatial detail was deemed beneficial to an effective traffic-to-highway assignment solution. To assist with this a geo-referenced database identifying the locations of zip code centroids within each county was obtained, allowing use of U.S. zip code business pattern ("ZBP") data (U.S. Census Bureau, 2014). Examination of this dataset identified a significant number of non-reporting (or suppressed data) gaps that questioned the validity of developing a similar level of commodity production and attraction totals for the zips involved. As an alternative, truck trip productions and attractions were first of all distributed across those zip code areas falling within corridor-adjacent counties on the basis of a zip code area employment, population, and annual payroll. With high correlations between each of the activity shares produced by these different measures, the disaggregation method selected for both trip productions and attractions was based on estimated employment in those zip codes reporting significant freight generating industries, i.e. on the basis of employment with the following industrial sectors: manufacturing, transportation, natural resources, wholesale, warehousing, construction, agriculture/forestry/fish/mining, retail, services, and other, i.e.

$$T(ci,cj) = T(i,j)^* \, [EF(ic)/\textstyle\sum_{ic\varepsilon i} \sum EF(ic)]^* \, [EF(ic)/\sum_{jc\varepsilon j} \sum EF(jc)] \qquad (3.10)$$

The resulting within-county shares are then applied to each of the five vehicle-class specific truck trip matrices produced by the process described in Section 3.5 below (i.e. the process of converting inter-county commodity tons shipped, from the trip distribution models, into truck class-specific O-D truck trip matrices). In doing so, this approach places a good deal of emphasis on the location of the truck trip loading and unloading points within a county. To assist this process zip code area centroids were selected to mirror known high truck activity locations in and around the Atlanta metro area. Given the limited number of within-county interstate access/egress points along the corridor this approach seems reasonable given the principal project objective of assigning trucks to appropriate stretches of the corridor's interstate highway.

3.5 Conversion of Commodity Tons Shipped to Truck Trips

Commodity tons shipped estimates were converted into number of truck trips, spread across five different truck size and configuration categories: single unit trucks, trucks with trailer, combination semi-trailers, combination double trailers, and triple trailer combinations.[12] Following the methodology described in Battelle (2011), and as applied in FAF3, commodity flows were shared across nine truck body types as well as five trip distance ranges. Figure 3.4 shows the steps involved.

First, the factors reported by Battelle are to distribute each commodity's O-D tons based on truck size class and O-D shipment distance interval. Next, these tonnage shares are converted into the number of trucks in each size class, also introducing a vehicle's body type into the process here to capture appropriate vehicle load factors. Up to nine body types are defined for each truck size class in the Battelle table. These body types are: *auto, livestock, bulk, flatbed, tank, dry van, reefer, logging and other*. Next, a factor for empty truck movements is added, again differentiated by both truck size class and body type. Finally, a summation is carried out across all body types, to get the number of truck trips per O-D-Commodity flow in each of the five vehicle size classes.

[12] Triple Combinations (estimated to be very small in number) were not operated on the I-85 corridor in 2007, and were treated as Combination Doubles in the present study.

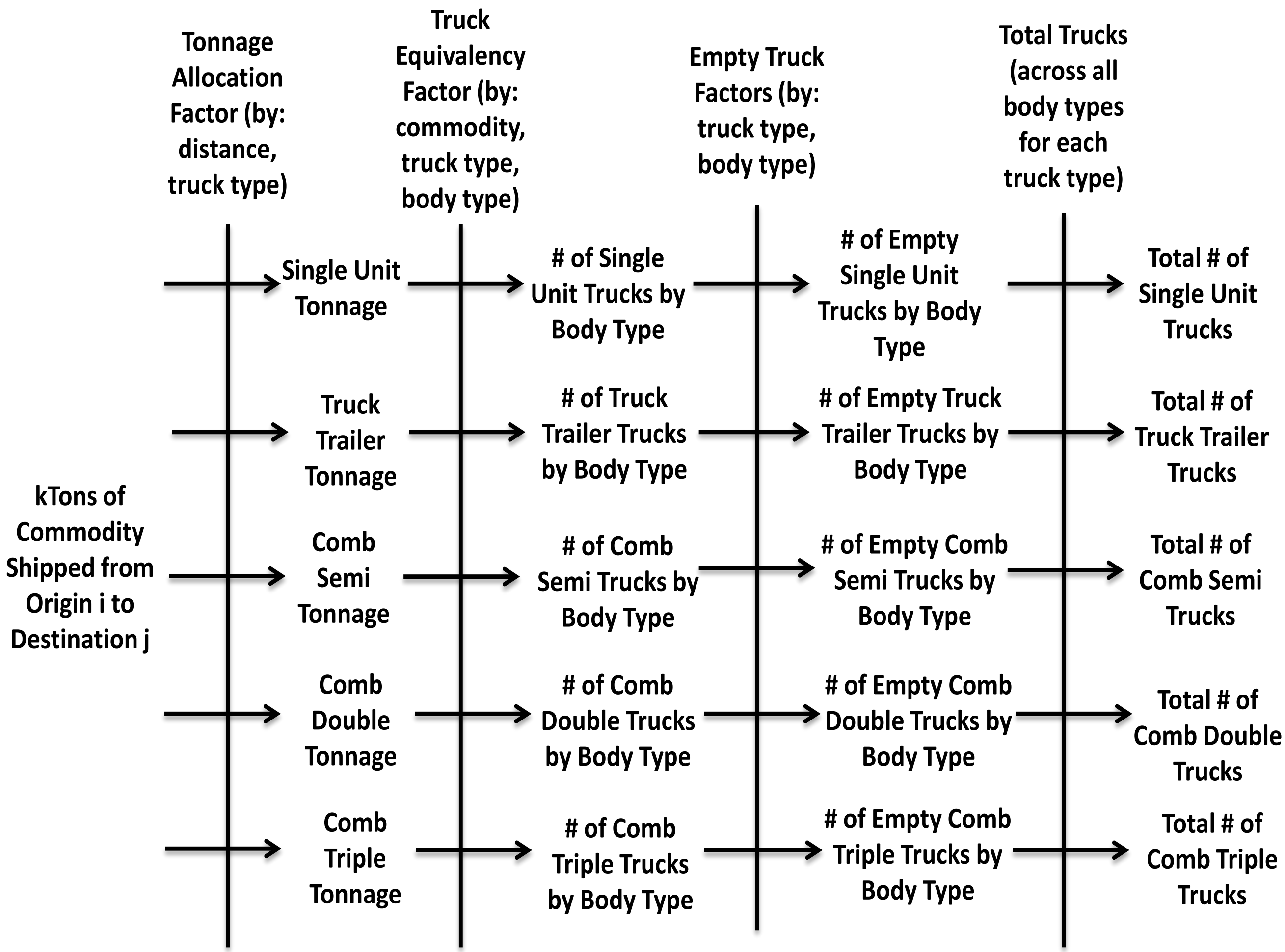

Figure 3.4 Steps in the Tons to Trucks Procedure

In the first step of this process five distance intervals are used to capture the differing probability of a truck of a given type (size class) making deliveries at different distances from its origination point. The five distance intervals used to capture this important effect are less than 51 miles, 51 to 100 miles, 101 to 200 miles, 201 to 500 miles, and more than 500 miles. At this point the result remains in commodity specific tons shipped by vehicle type. The truck equivalency factors used to relate these commodity tons to number of truck in size class 'v' is then computed as (Battelle, 2011):

$$Y(v) = \sum_{k=1,9} \{(X(Cv) * \beta (Cvk)] / \omega(Cvk) \} \quad (3.11)$$

where, $Y(v)$ = number of trucks of truck type v
$X(Cv)$ = tons of commodity C moved by truck type v
$\beta(Cvk)$ = the proportion of commodity C moved by truck type v with body type k
$\omega(Cvk)$ = the average payload of truck type v with body type k transporting commodity C

The empty truck loading factors are meant to capture the proportion of trips in a vehicle category that engage in empty back-hauls and empty vehicle repositioning legs, and take the form:

$$E(v) = \sum_{k=1,9} \{[X(Cv) * \beta(Cvk) * E(vk)] / \omega(Cvk) \} \quad (3.12)$$

where, E(v)= number of empty trucks of truck type v; and E(v,k) = empty truck factor for truck type v with body type k

Total truck trips of type v assigned to a specific O-D-Commodity flow are then computed as:

$$Y(v) + E(v) \quad (3.13)$$

where Y(v) = number of payload carrying trucks of type v; and E(v) = number of empty trucks of type v.

For further details of this multi-step ton-to-truck conversion procedure see Battelle (2011), which can be downloaded from FHWA's FAF3 website. The report also contains the many conversion tables required to produce these commodity-and-distance determined truck traffic estimates. Of note, the various truck distance interval, payload, and empty truck trip factors derived and reported in the tables published in Battelle (2011) are based on data from the U.S. Census Bureau's 2002 Vehicle Inventory and Survey (US Census, 2004). With the loss of the VIUS data collection program since that time, an update to these conversion factors is clearly needed at the present time. This FAF3-based procedure was used here because it represents the most detailed and fully documented procedure of its type to date, and because it offers consistency with the use of the FAF3 dataset as a source for regional O-D control totals and estimated network traffic loadings.

3.6 Example Model Outputs

The principal output from this stage of the model development effort is a set of O-D-Commodity flows and their conversion into O-D-V (i.e. Vehicle class) based flows. Figure 3.5 shows an example mapping of truck flows within the south-east region, color coded by whether a flow occurs entirely within the state of Georgia (shown in brown), begins inside and ends outside Georgia (flows in yellow), begins outside and terminates inside Georgia (flows in purple), or begins outside and simply passes through Georgia (shown in teal). The flows shown are all those that the modeling assigns to I-85/I-285 for some portion of their route. The method for extracting these O-D flows is described in Chapter 4 below.

Turning to a series of graphs, Figure 3.6 shows the top twelve commodity classes assigned by the spatial allocation model to the I-85 corridor, distinguishing between commodities that start out in Georgia and those that terminate at a destination within the state (including shipments that are internal to, i.e. that both

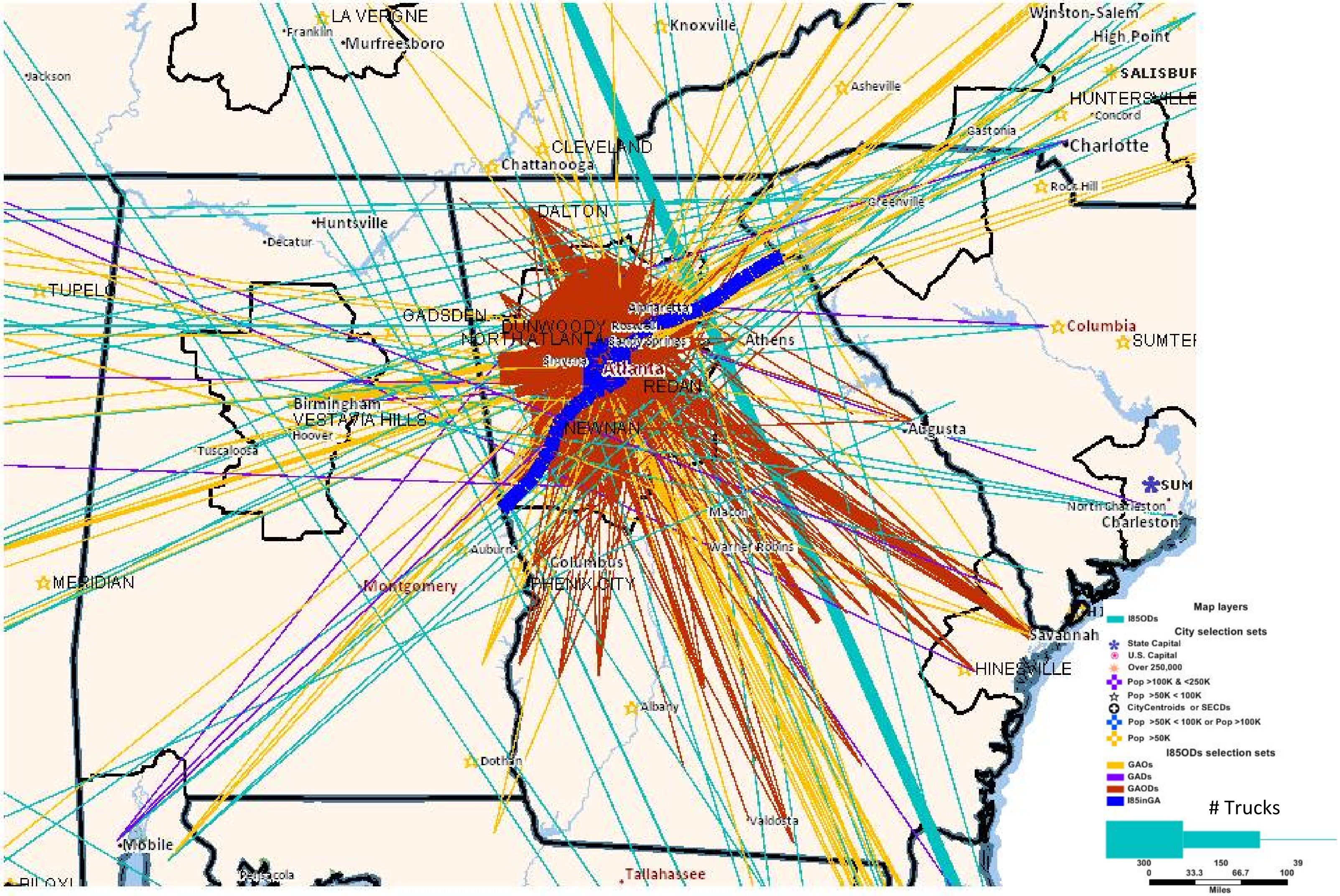

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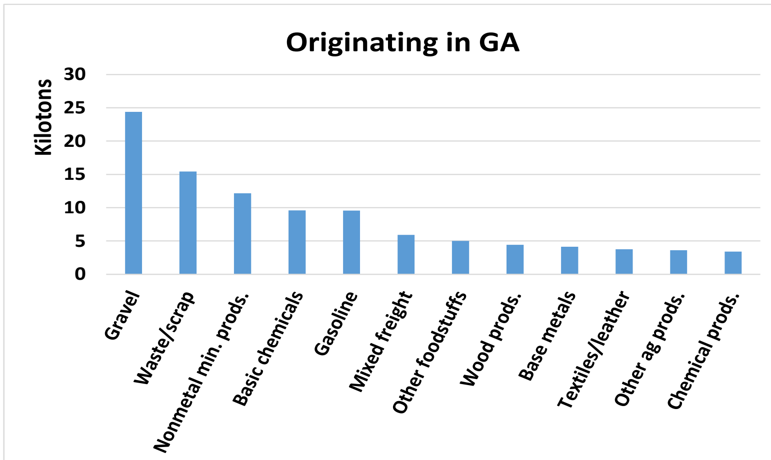
Figure 3.5 Example Mapping of Truck Flows That Use I-85/I-285 within Georgia

start and end in, Georgia in both cases). Hence the dominance of gravel tonnage, which was the principal commodity moved within Georgia by weight in 2007 (and in 2012), and of which 93% represents shipments occurring entirely within the state, according the FAF3. Commodity value-wise, Machinery, Electronics, Motor Vehicles, Textiles and Leather, and Pharmaceuticals were the top 5 commodities shipped by value, both into and out of Georgia along I-85/I-285 in 2007 (see Chapter 4 for more details).



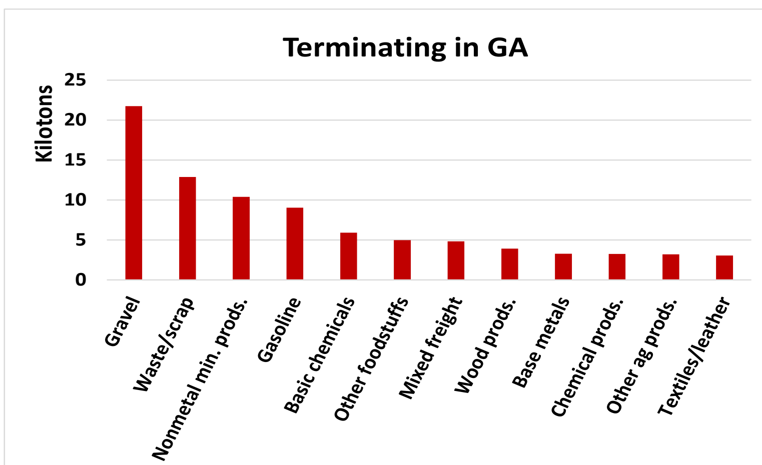


Figure 3.6 Principal Corridor Commodities by Tonnage in 2007

Figure 3.7 below shows the sort of results obtained from the subsequent commodity tons to-truck trip conversion process described in Section 3.5. Recognizing that no definitive reporting of these O-D flows exists, in each case the data behind these graphs and mappings was used to assess the reasonableness of the flow volumes generated, by drawing comparisons to previous estimates of such flows from other (also model-generation assisted) sources reported in the literature.

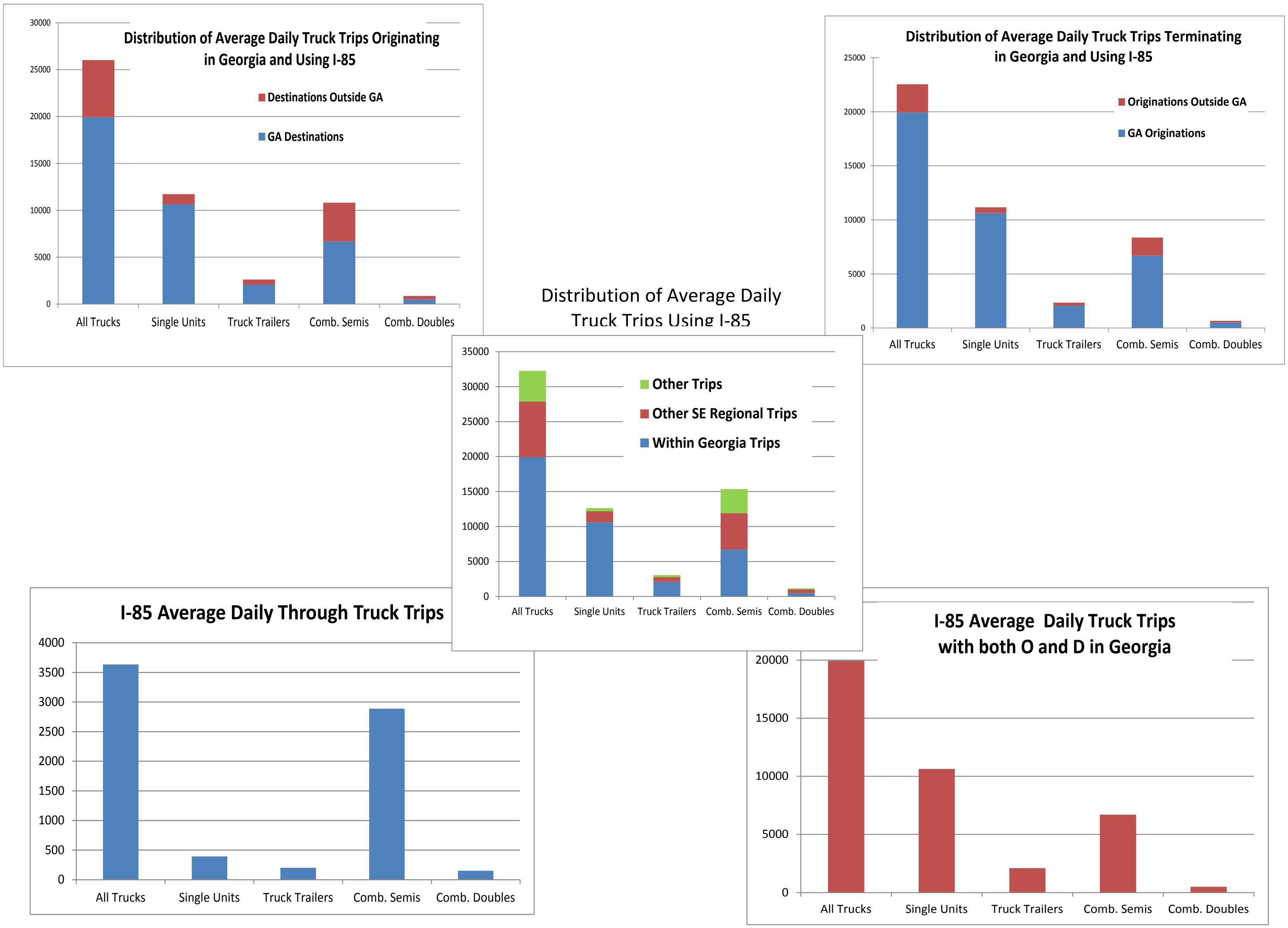


Figure 3.7 Example Model Estimated Daily Truck Trips Volumes on I-85 (in 2007) by Truck Type

3.7 References

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Chapter 4: Putting a Value on Corridor Truck-Freight

4.1 Introduction

Given a set of origin-destination-commodity (O-D-C) flow matrices, the next project task involved assigning these flows to most likely routes over the U.S. highway network. A variety of congestion-sensitive traffic route assignment models now exist for this purpose. Some of these models have seen extensive use within multi-year planning model applications, with a growing attention over the past two decades given to the routes being used by commercial trucking (see, for example, Alam et al, 2007; Battelle, 2011; Boile et al, 2000; Boyce and Yei, 2013; Bujanda et al, 2012; Chow et al, 2012; Hadi et al, 2011; Quattrone, 2008; Rowell et al, 2012; Rowinski, et al, 2000; Stone et al, 2009; Unnikrishnan and Figliozzi, 2012; Wu et al, 2006; Ye, 2010). This chapter describes the development and application of the I-85 corridor-based truck route assignment model and how it was linked in an iterative fashion to the commodity flow models described in Chapter 3.

4.2 Multi-Class Origin User Equilibrium (OUE) Assignment

Recognizing that no assignment procedure can at present guarantee the accuracy or superiority of its O-D based route assignments over all traffic conditions and network configurations, for our study the origin-based user equilibrium (OUE) multiclass traffic assignment routine provided by the TransCAD commercial GIS/Transportation Planning software (Caliper Corporation, 2012) was used to assign origin-destination-vehicle class (O-D-V) flows to the I-85/I-285 corridor through Georgia. This algorithm, which has evolved out of research by Dial (1999, 2006) into path-based assignment methods, was selected for its ease of use within an established GIS platform, including the ability to carry out a *select link analysis* that relates a specific set of O-D flows to specific network (corridor) links; and because it makes use of the principle of "proportionality", which helps to ensure that differences in route and class link flows based on different input scenarios do not become "artifacts of the manner in which the assignment was set up" (Boyce and Wei, 2013; see also Boyce and Bar-Gera, 1999; Bar-Gera, 2002 and Bar-Gera et al, 2012; and Slavin et al, 2006, 2010).

The ability to link commodity specific O-D-Vehicle Class based flows, each with a potentially different value attached to the importance of travel time, to specific sections of highway, proves very useful when trying to evaluate the impacts of both recurring and incidence-induced congestion delays on the costs of goods deliveries. The issue of proportionality is a little more involved, at least from a conceptual standpoint. Boyce and Wei (2013) define this condition as follows: the proportion of vehicles on each of any two alternative, equal-cost multi-link sections of highway should be the same, regardless of their user (here, truck size) class, trip origin or trip destination, and go on to show examples of how this can prove to be important in practice for ensuring greater consistency between a before- and after- network or O-D flow modification to the assignment process. To what extent this notion of proportionality is an empirically sound assumption across a range of network configurations and traveler responses currently requires additional empirical testing, but it does appear to offer traffic routing results that are in line with past assignments when examined at the link volume level. The OUE approach to assignment model calibration also offers a third benefit: the opportunity to achieve high levels of convergence towards link flow stability in reasonable computational time, removing one more potentially unwanted source of model application-induced discrepancies between alternative traffic flow scenarios.[13]

4.3 Linked Distribution-Assignment Modeling

In order to capture the effects of changes in travel costs, including travel times, on the subsequent allocation of truck movements between origin-destination pairs of places, an iterative procedure was used to feed the results of the OUE assignment model back to the O-D-Vehicle Class matrix of flows described in Chapter 3 above. Figure 4.1 shows this linkage, distinguishing between the treatment of External-External (E-E) or through-region flows, Internal-External (I-E and E-I), and Internal-Internal (I-I) flows: where Internal refers here to flows between counties within the six state south eastern region (i.e. within AL, FL, GA, NC, SC and TN). In order to ensure realistic levels of traffic congestion on individual sections of highway, the automobile and “non-FAF”[14] commercial traffic estimates, in the form of AADT link counts provided by FAF3 were pre-loaded onto the regional highway network, before attempting to assign truck flows.[15] Prior to assignment these truck size class-specific O-D flows (which include returning or deadheading empty trips) are first converted to congestion relevant passenger car equivalents (pce). After some experimentation, the truck type specific pce conversions reported in *Heavy Vehicle Effects on Florida Freeways and Multilane Highways* (Washburn and Ozkul, 2013) were applied, based on Highway Capacity Manual equations for various roadway grades and various proportions of trucks and buses. The modeler faces a challenge here when running a static traffic assignment routine that does not make use of information on when trucks access the network. That is, while the timing of many truck trips is determined by the scheduling needs of the receiving industries, others may have the option

[13] Based on the findings reported by Boyce et al (2004) and Slaving et al (2006), the OUE assignments were run until a relative gap of 0.01% (0.0001) was achieved, in order to achieve link flow stability.

[14] These are AADTTs that were added to the FAF link assignments because the FAF3 assignment modeling could not be fully reconciled with the traffic counts reported by states as part of the FHWA’s Highway Performance Monitoring System (HPMS) traffic reporting program. See Battelle (2011) for details. Given the present study’s focus on strategically important and Interstate centered freight corridors, these non-FAF, highly localized flows were not modeled explicitly at this stage.

[15] This is also another reason for using the OUE procedure, which gets around the problem of vehicle class-specific flow shares being re-assigned across competing links/routes as an artifact of the order in which such classes are loaded onto the network (i.e. producing a different set of vehicle class-specific allocations to links for the same, total pce-based equilibrium link loadings).

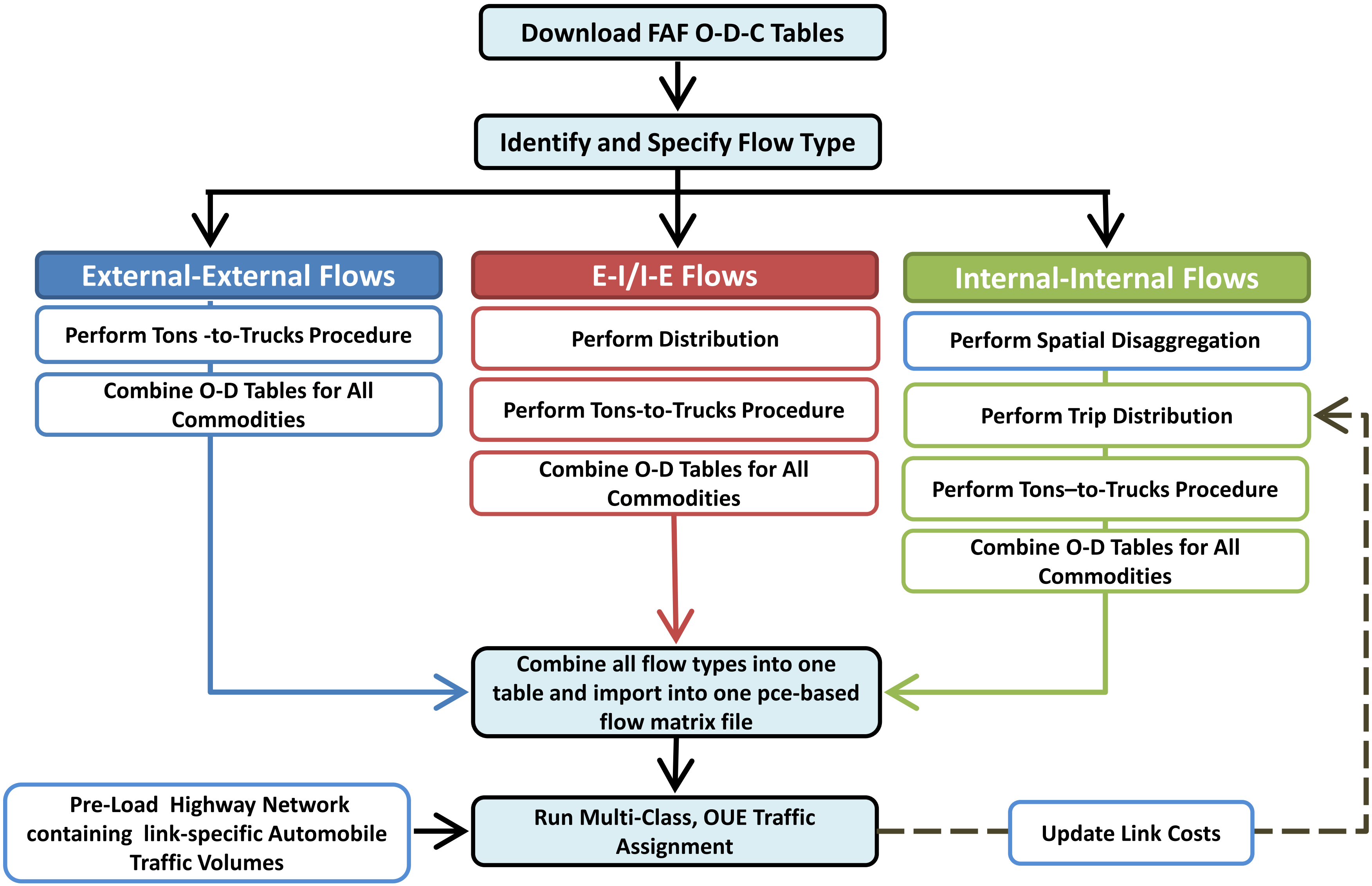


Figure 4.1 Linked Truck Trip Distribution and Network Assignment Modeling

of selecting the best time to traverse the corridor based on known time-of-day as well as location specific traffic bottlenecks. The assignment model runs reported below used the peak period travel time estimates, expanded to daily truck movement totals, as an approximation to the costs of congestion experienced by trucks moving through the I-85 corridor's major bottleneck locations.[16] For the most part, in 2007, interstate speeds were on the order of 60 mph along the rural sections of I-85 within Georgia, with significant peak period congestion limited for the most part to movements within and around the Atlanta metro area, including flows on I-285 around the Atlanta urban core. This approach does not, however, fully account for local congestion such as may occur during 'first mile-last mile' Interstate access and egress A fully developed, hour by hour simulation of truck movements along the corridor would be required to capture the true range of truck travel times, based on when and where such trucks enter the corridor over the course of the day. A more accurate method in the future could use a dynamic traffic assignment model, given suitable time of day traffic flow data from a source such as GPS truck tracking, combined with data from well positioned hourly traffic counters. Such detailed time-of-day data was not available to the current project, although a validation of the reasonableness of model generated traffic volumes was carried out by comparing them against Georgia DOT reported truck and mixed traffic counts along I-85 and I-285 in 2007[17], while model estimated traffic speeds were compared to average hourly I-85 and I-285 highway link speeds derived from 2008 GPS data collected by the American Transportation Research Institute (ATRI)[18]. While not ideal, this approach is seen as a reasonable sketch planning approximation to a more detailed (and more data intensive) multi-time period traffic assignment model application of the disaggregated commodity flows matrix generation method described in Chapter 3.

Two methods for estimating route selections using this assignment approach were investigated. Method 1 based its route selection on travel time considerations only. Method 2, and the one used in reporting of empirical results below, based vehicle class (v) specific route selection on a generalized link travel cost formula of the form:

$$\mathrm{OC(v,i,j)} = \sum_{l \in \mathrm{L(v,i,j)}} \left[\left(1 + \frac{0.26}{0.73}\right) [labor(l) + fuel(v,l)] \right] \tag{4.1}$$

where,

- OC(v,i,j)= operational cost from origin i to destination j using truck type *v*
- l = link
- L(v,i,j) = set of links on the shortest path from i to i using truck type *v*
- $labor(l)$ = (labor cost along link *l*) = $\$23.15/_{hour} * t(l)$
    - t(l) = travel time along link l in hours
- *fuel (v,l)* = fuel cost for truck type v along link *l*

[17] http://www.dot.ga.gov/DS/Data
[18] https://www.freightperformance.org/fpmweb/user_login.aspx

- $S >= 55\ mph$: $\frac{\$2.88}{gal} * d_l \ / \left[\frac{1}{(1.53\times10^{-6}\times M_v)+(2.94\times10^{-5}+1.94\times10^{-13}\times M_v)\times S_l^2}\right]$ (4.2a)

- $S \leq 55\ mph$: $\frac{\$2.88}{gal} * d_l / \left[\frac{33{,}000}{M_v}\left[\frac{1.536}{0.17+\left({2.43}/{S_l}\right)}\right]\right]$ (4.2b)

- M_v = truck weight of truck type v in pounds
  - SU weight = 40674 lbs
  - TT weight = 42730 lbs
  - CS weight = 65974 lbs
  - CD weight = 76128 lbs
  - CT weight = 127882 lbs
- S_l = truck speed along link *l* in mph and d_l = length of link *l* in miles

and where 73% represents the portion of the operational costs that labor and fuel make up, while 26% represents the other costs of operating and maintaining a truck (minus 1% for tolls).

Both methods used versions of the Bureau of Public Roads ("BPR") link cost function, i.e.

$$t * \left[1 + \alpha\left(\frac{x}{C}\right)^{\lambda}\right], \tag{4.3}$$

where

- t = free flow travel time
- C = capacity
- x = flow
- α = coefficient
- λ= coefficient

The values used for α and λ were taken from Horowitz (1991). As it pertains to this project, these coefficients were assigned to the different functional classes (FCLASS) in the FAF network, based on facility type (i.e., freeway or multi-lane highway) and speed, as follows:

Table 4.1 Facility Function Class-Based Delay Function Parameters

FCLASS	α	λ
1, 11	0.88	9.8
12	0.83	5.5
0, 2, 6, 7, 14, 16, 17	0.71	2.1

Which approach, i.e. a generalized cost-based or time-based approach, to route selection is behaviorally more realistic is again an open question at the present time. Certainly we would expect both trucking firms and shippers to base decisions on bottom-line dollar costs to move the goods.

However, route selection may often be a decision made at the time of shipment, especially as real time data on existing and anticipated traffic conditions becomes more widely available.

4.4 Using Select Link Analysis to Estimate the Value of Commodities Moving on I-85 in Georgia

Example results from iterating the 43 commodity flow (truck trip distribution) models and multi-class traffic assignment model to a stable equilibrium are presented below. These results are based on the use of equation (3.7b) to represent perceived trucking costs in the distribution models, and using equations (4.1) and (4.2) above, which routes truck traffic over the network on the basis of a generalized travel cost.

After applying the iterative trip distribution-OUE assignment routine shown in Figure 4.1, selected link analysis was used to identify the set of O-D flows assigned to the I-85 corridor’s links. That is, all O-D truck flows are identified that make use of I-85 (including I-285 around Atlanta) within the state of Georgia for any part of their journey. The commodity flows identified by the trip distribution models are then used to identify the commodities associated with these truck trips in order to assign an approximate value to the goods shipped. Using the results of this process, along with the average per ton dollar values of inter-regional freight reported in the FAF3 dataset, estimates of the dollar value of truck freight transported over the within-Georgia portion of the I-85 corridor in 2007 were derived as follows:

$$\$ \text{ Value of O-D-Commodities Carried} = \sum_i \sum_j \sum_C \text{Tons}(i,j,C) * \$/\text{Ton}(i,j,C) \quad (4.4)$$

where the summation is over all SCTG level 2 commodity classes, C=1,2….43, and:

$$\$/\text{Tons}(i,j,C) = \$/\text{Ton}(\text{FAF3I},\text{FAF3J},C) \quad (4.5)$$

where origin i is located within FAF3 region I, and destination j is located within FAF3 region J, and where an origin and a destination in this instance can be a within south-eastern county or a FAF3 external analysis region (i.e. i = I and j = J for external trip ends). Table 4.2 provides summary results for a representative model run.

In addition to the estimated dollar value of the goods being transported on the Interstate, Table 4.2 also shows the estimated cost of vehicle operation in moving these commodities from origin to destination, based on operating costs derived using equations (4.1) to (4.3) above. These operating costs are estimated to represent 2% of the value of the commodities transported. This does not include any costs to shippers, carriers or receivers due to travel time (and hence arrival time) unreliability.

This topic is dealt with in Chapter 5 below. [19]

Table 4.2 Example Corridor O-D Summary Statistics

Commodity $ Value Carried /Day	1,108,636,556
Number of Daily Truck Trips	36,784
Tons Carried Daily	693,613
Av $ Value/Ton Carried	1,598.3
Av. $ Value/Corridor Truck Trip	30,139
Daily Vehicle Operating Cost ($)	23,028,868
$ Transport Cost as % of $ Value	2.08%

Figure 4.2 shows the composition of these commodity flows, based on the 43 2-Digit SCTG commodity classes used described in Chapter 3. The two figures on the left-hand side show the distribution of the top 25 commodity classes, ranked by dollar value and by kilotons transported respectively, as assigned to the corridor by the distribution-assignment model. The two figures on the right-hand side show the same rankings for all freight moved within the nation in 2007, according to FAF3. As expected, commodity rankings differ, in part because of the Interstate, within Georgia only focus of the corridor study, but also because of regional differences in the movement of commodities.

Even so, twenty of the top 25 commodities shipped by weight are the same within the corridor and nation, but with cereal grains, natural sands, fuel oils, coal, non-metallic minerals, and “unknown” showing up in the national picture, replaced by newsprint/paper, paper articles, textiles/leather, meat/seafood, milled grain products and miscellaneous manufactured products within the corridor.

Figure 4.3 below shows the ranking of these same commodity classes on the basis of $/ton, with the bottom diagram placing the $/ton values for the corridor and FAF3 side by side, showing a general but not universal similarity in both commodity values and rankings. Rankings, as might be expected, are similar across the two flow geographies, with 24 out of the top 25 commodity classes and the top 10 commodities being the same, but with some noticeable differences in average $/ton values between corridor and nation among the most valuable four commodity classes: of which pharmaceuticals and transportation equipment play a significant role in the corridor’s overall freight flow valuation (i.e. per the top left diagram in Figure 4.2).

Finally, as another point of comparison, Figure 4.4 shows the difference in the corridor assigned commodity breakdown and a similar breakdown for all truck tonnage flows into, out of and within Georgia in 2007, according to the FAF3 national database. While there is a general similarity in the two commodity rankings, it is clear (as expected) that logging products play a much larger role in

[19] This 2% figure is in line with reporting of the transportation costs as a percentage of sales revenue, as reported by, for example, Mandrel (2004), Holcomb and Manrodt (2011), and Tompkins and Ferrell (2011).

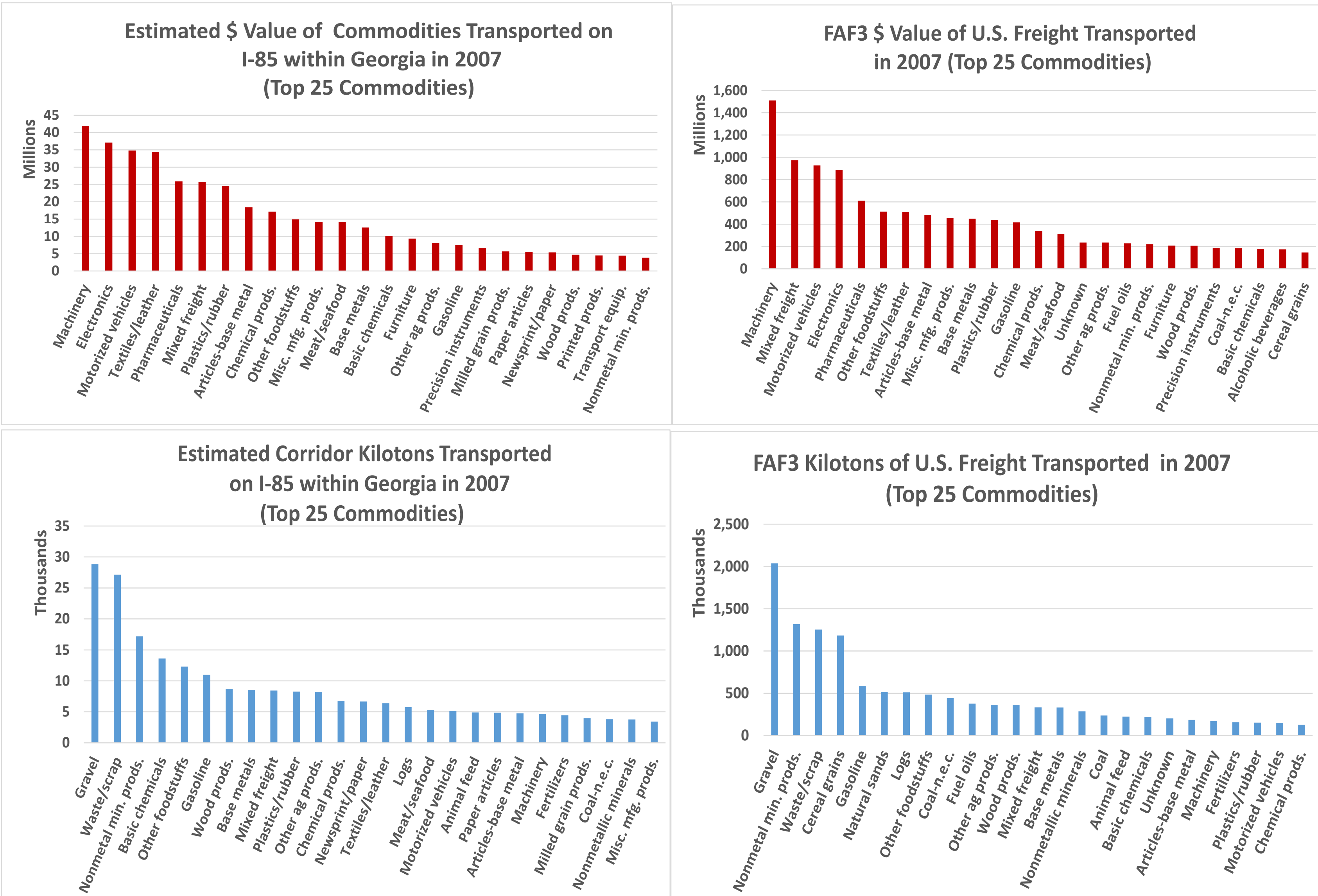
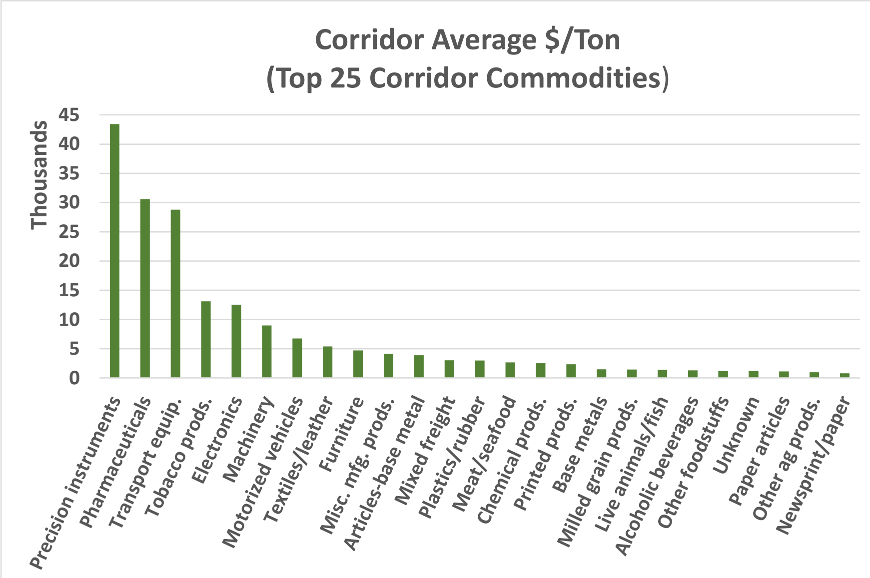
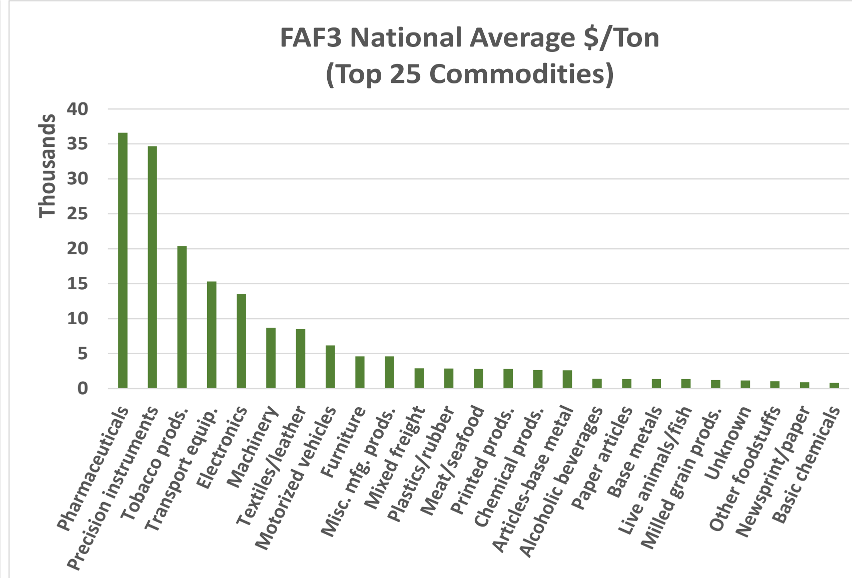


Figure 4.2 Estimated Commodity Dollar Values and Tonnages Shipped in 2007: Corridor vs U.S. Comparisons





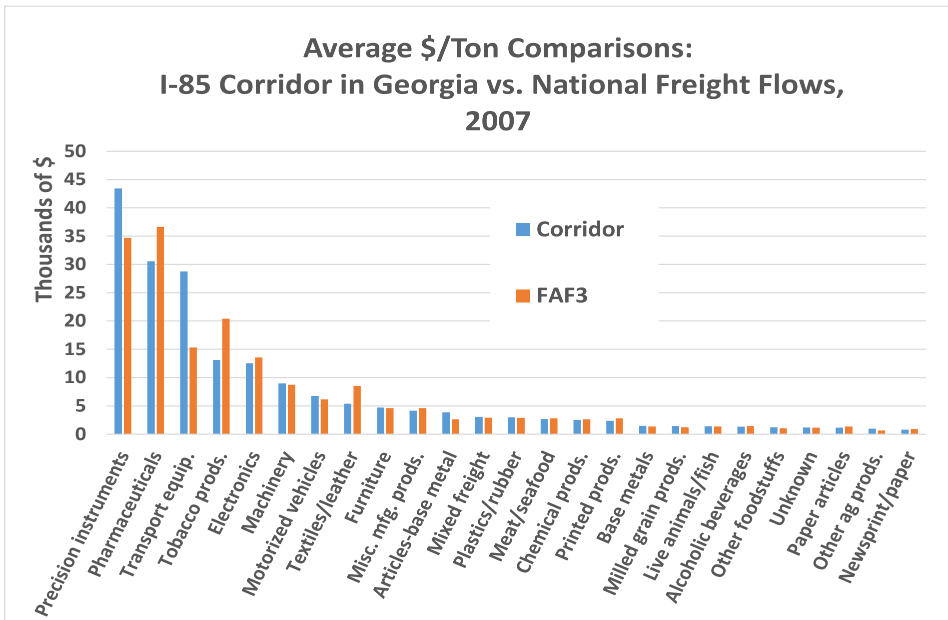


Figure 4.3 Estimated Dollar per Ton Commodity Values: Corridor vs U.S. Averages

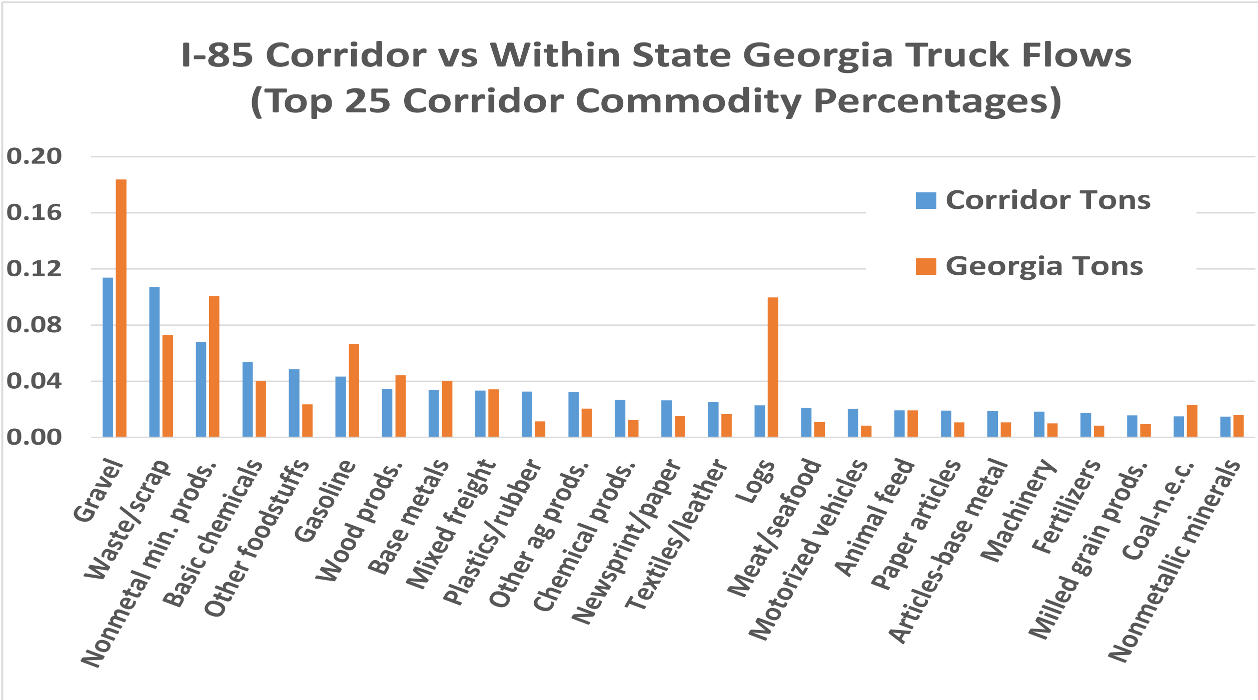


Figure 4.4 Corridor vs. Statewide Commodity Flows Comparison

Georgia freight transport overall within the state, as does gravel and other nonmetallic mineral products, and gasoline transport. The corridor in turn transports more than its share of Waste/Scrap and Other Foodstuffs, in particular. This is consistent with the location of the state's producing and consuming industries, and with the rankings reported in, for example, the Georgia Statewide Freight and Logistics Plan, 2010-50 (Georgia DOT, 2015).

Ideally, such comparisons would be done for different freight significant corridors around the region and nation, using a State's borders to limit the O-D-C flows considered as done here, or using other broader (multi-state) or narrower (e.g. MPO-based) regional definitions. This represents future work. The present project results, however, do show some interesting differences. In particular, while the 2007 FAF3 produces an estimated national average value of $914.3 per freight ton, this section of I-85's corridor flows is estimated to have a significantly higher average value of $1,598 per ton. Recognizing that the $/ton statistics used to generate this result rely on FAF3 O-D-C regionally averaged values for those (highly disaggregated) O-Ds assigned to the corridor, this still suggests a much greater than average value of corridor-supported goods movement: a result of interest to studies of the value of truck freight time delays, including the analysis presented in Chapter 5 of this report.

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Chapter 5: Estimation of Corridor Truck Travel Delay Costs

5.1 Introduction

Cost savings due to reduced travel times typically represent the largest share of the monetary benefits associated with projects that add substantial capacity to heavily trafficked highways. A significant percentage of such savings are often attributable to truck movements. Forecasts of both passenger car and truck traffic growth suggest that, without adding highway capacity or diverting significant amounts of freight to other modes, highway congestion will spread well beyond current urban centers over the next two to three decades, impacting many inter-city and other long-haul transportation routes (Battelle, 2011). The costs of such congestion are already impacting the trucking industry adversely. Pierce and Murray (2014) estimate that some 141 million truck operating hours were lost to congestion across the United States in 2013, at a cost of over $ 9.2 billion[20]. Much of this truck traffic uses the nation's Interstate Highways, whose maintenance and efficient operation is essential to the movement of goods between U.S. cities and states. These Interstates represent the backbone of many strategically important freight corridors, as pointed out by the federal government's 2012 MAP-21 and 2015 FAST legislation. It is perhaps a little surprising therefore that planners within State DOTs and MPOs don't have a widely used and well established data analysis and modeling tool for quantifying the monetary impacts of traffic congestion along such corridors: impacts that are based on the types of commodities being moved along them, and the types of industries producing and consuming this freight.

Building on the commodity flow and network assignment modeling described in Chapters 3 and 4 of this report, this chapter describes an approach to estimating the monetary costs associated with corridor level truck travel time delays, again using 2007 data for the I-85 corridor in Georgia as a case study. The motivation for this effort was to try to assign a value of travel delay to a specific highway corridor, in the form of a freight performance measure that complements the value of freight transported measures described in Chapter 4. For both empirical and conceptual reasons this is currently a difficult task, and the results of the present study are meant primarily to highlight these issues, while demonstrating the potential for improved estimates of performance as new and better data sources become available. To this end, Section 5.2 below summarizes the results of an extensive literature review of recent approaches to measuring the time-based monetary costs of truck freight movements. See the review by Southworth (2016) for a more extensive presentation of this literature, and from which the material in this section was drawn. Section 5.3 then describes a method that uses estimates drawn from this literature to represent the considerable range of trip time valued savings attributed to different commodity classes, different vehicle types, and different trip lengths, computed on a trip origin-to-destination basis. The emphasis here is on the use of existing data sources and an easy to implement methodology. This approach is used to generate an example set of travel time delay

[20] with over $275 million attributed to congestion within the Atlanta, GA metropolitan area.

costs for the I-85 case study, including the potential costs of both recurring and unexpected congestion induced delays on the reliability of on time vehicle arrivals.

5.2 Recent Truck Freight Value of Time Studies

5.2.1 Key Cost Factors: Truck Trip Duration and Arrival Time Reliability

The economic costs of delays and disruptions to freight movement are well documented and are testimony to the often used phrase that "time is money". In 2005 the Federal Highway Administration released a flyer with the following statement (FHWA, 2005a):

"Research on the trucking industry shows that shippers and carriers value transit time at $25 to $200 per hour, depending on the product being carried. Unexpected delays can increase that value by 50 to 250 percent. Timely, reliable goods movement allows businesses to reduce manufacturing and inventory costs and to improve responsiveness to rapidly changing markets and consumer desires."

Key words in the above quote are *timely* and *reliable*, indicating the importance of consistency in on-time vehicle arrivals at both cargo pickup and delivery locations. Depending on the type of industry and commodity involved, "reliable" service may mean arriving at the customer's business location on a regular repeat basis, arriving within pre-arranged pickup or delivery time windows, and/or being able to respond quickly to last-minute requests for service in a timely manner (reflecting service flexibility). Past studies indicate that such reliability in truck arrival times, whether for pickup or delivery, is often as, or more important than the cost of the freight shipment per se. As Holl (2006, page 11) puts it, in addressing the role of regional transportation infrastructure investments from the individual firm perspective:

"*New patterns of production and distribution are emerging that are increasingly dependent on high-quality transportation. In an increasingly time-based competitive environment, access to the higher order road network and issues of reliability and frequency are becoming more important than just pecuniary transport costs*."

The wide range of possible travel time valuations associated with truck freight movements, such as the range quoted above, currently poses significant problems for transportation planners involved in both freight traffic forecasting, and highway expansion project cost-benefit analyses.

Complicating the matter is the number of different freight agents involved: freight shippers, carriers, receivers, and brokers. This raises the question of whose value of time is being, or should be measured, with the relevant time-based cost elements differing by type of freight agent. Hence, a shipper with its own trucking fleet is faced with time-related costs for both the cargo carried and the vehicles used to transport it. Depending on its business practices, notably the likelihood of having to maintain inventory because of shipment delays, the shipper may also incur additional costs not directly associated with vehicle operation. In contrast, a for–hire carrier is concerned largely with vehicle operating costs, including driver time, and with lost opportunities for additional use of these vehicles if significant delays occur (Hensher et al, 2007; Massiani, 2008; Significance, 2007; Gong et al, 2012). Third, receivers of freight may put yet another valuation on a particular delivery service, with some receivers' business operations being "inventory light", and as a result highly dependent on just-in-time product deliveries. And with many shippers also acting as receivers of goods, especially those firms who receive raw materials and send out fully or partial manufactured goods, supply chain efficiency may depend more or less heavily on keeping to a minimum any truck arrival delays, at either end of the company's input-output process. Complicating the issue further, a fourth freight agent may also be involved in the form of a freight broker, such as a third party logistics (3PL) company, who sets up a carrier-shipper agreement to move the goods. The nature of the contractual arrangements among these various freight agents is also important. Who bears the burden of late (or early) delivery costs, if any, can affect the choice of mode, vehicle type, and perhaps also routing. While such decisions are made by the shipping firm where private carriage is concerned, in the case of for-hire carriage one or more of these choices may devolve to the carrier. And a trucker operating on a per mileage basis is likely to be more concerned about traffic congestion-induced delays than a trucker operating on an hourly wage. In addressing these issues, past value of time studies have either separated their efforts according to the type of freight agent under study, or have treated freight time costs as impacting the freight movement industry at large, by assuming that any travel delay-based freight costs are to be avoided, however the transfers of responsibility for such costs are distributed across the various agents involved.

Looked at in a positive light, ICF Consulting and HLB Decision-Economics (ICF/HLB,2002) refer to the "second-order benefits" of highly reliable, on-time freight transportation that supports savings in a company's cargo handling logistics (transport, warehousing and related inventory-holding activities), possibly leading to the use of money saved to increase a firm's (i.e. a shipper's and/or receiver's) industrial output. FHWA (2004) suggest that these second-order impacts, which are especially relevant to multi-million dollar (including inter-modal) infrastructure investment proposals, may add an additional 15% to the direct traffic delay-reducing benefits of infrastructure investments.

In carrying out cost-benefit studies for long range planning purposes, a study's time horizon can also affect which travel time delay-based cost elements, to include. Over time, consistently poor on-time delivery service may lead a shipper to change its carriers (and perhaps also brokers), and/or lead to a receiver switching its suppliers: while a more extreme receiver/customer response to such concerns is to move once out-sourced production processes into the main manufacturing plant. In some instances, if the shipper or receiver is the party regularly responsible for delays in the freight handling process, a carrier may also choose to look elsewhere, for business that makes more productive use of its vehicle fleet.

Going one step further, it has also been suggested that noticeably improved on-time service reliability can in some cases lead, over time, to a broader reorganization of company logistics practices, producing "third-order benefits" that range from 10% to 40% savings in overall logistics costs (see also ICF/HLB, 2002; CSI et al, 2006). However, nearly all value of freight time studies to date have focused on measuring the direct and second-order impacts on company logistics costs, with the second-order impacts closely associated with the variability in truck on-time performance. This (arguably conservative) approach is the one followed here. In what follows we use FVOT to refer to freight value of time as it reflects the direct impacts on movement costs of additional, congestion impacted trip duration; and use FVOTR to refer to the value of on-time vehicle arrival (un)reliability, with the latter usually expressed through a measure of variability in trip times over a suitable time period, such as pickups or deliveries over a season or a year, and with both indices measured on a dollars per hour basis.

5.2.2 Estimation Methods: FVOT and FVOTR

Most past value of travel time studies, whether focused on passenger, freight, or mixed traffic movements, are carried out as either (a) inputs to cost-benefit analyses of transportation infrastructure expansion or re-designation projects, notably to put a monetary value on any time savings obtained through reduced traffic congestion, or (b) for the purposes of forecasting, as a means of understanding and quantifying the effects of these time savings or losses on the freight-producing decisions made by shippers, receivers and carriers. Not surprisingly then, past efforts to place a suitable value (or range of values) on truck, and more broadly freight, travel time can be placed into two broad categories (Kawamura, 2007; Zamparini and Reggiani, 2007; Gong et al, 2012; de Jong, 2007, 2014):

1. Methods well suited for cost-benefit analysis, based on factor-cost estimation, including increasingly sophisticated and detailed inventory based cost accounting, and

2. Methods suited to freight demand estimation and forecasting, based on the concept of willingness-to-pay for time savings, using empirically calibrated freight demand models to capture the importance of time saved or lost to individual freight agents, by quantifying the trade-off between time used and monetary operating costs.

Both approaches have their strengths and weaknesses, with the factor cost based method finding it difficult to quantify the monetary impacts of service unreliability, which in turn makes it difficult to incorporate the broader logistical costs associated with freight handling and truck fleet asset utilization in the presence of unreliable on-time pickups and deliveries. And while the freight demand-based modeling studies offer a popular approach to capturing the importance of service reliability on supply chain logistics, they do so via costly and often difficult to obtain survey data, based on limited sample sizes that are usually industrial sector, geographic context, and/or class of freight agent specific. The key findings from this review are the following:

5.2.2.1 The Factor Cost Method puts a monetary value on all time dependent input factors that are affected negatively by delays in product deliveries. Differences across studies are largely concerned with which cost factors to include, and in particular whether to quantify only in-transit vehicle operating costs, or to extend the analysis to capture the effects of unreliable travel times on the freight handling activities at either end of a trip.

In-Transit Delay Costs. In terms of in-transit (i.e. over the highway or "en route") operating costs, past studies have used different combinations of per hour labor (mainly driver payroll) costs; vehicle and cargo depreciation costs; cargo (or inventory carrying) costs; fuel and other fixed or variable vehicle operating costs; or, when known, the freight rate charged - to assign time-related costs to truck trips. For the most part these differences stem from different interpretations of what represents a time-impacted cost factor. As noted by de Jong (2007):

"There is no consensus on the issue whether fixed cost of transport equipment, overheads and non-transport inventory and logistic cost should be included".

The study by Torrey and Murray (2015), in the latest in a series of annual updates carried out by the American Transportation Research Institute (ATRI), provides a nationally averaged per mile truck operating cost of $1.7, which at an average industry-vetted operating speed of 38.9 miles per hour leads them to suggest an average of $68 per truck operating hour. This includes fuel, labor, vehicle or trailer leasing or purchase costs, repair and maintenance and truck insurance premiums, licenses and permits, tires, and any tolls paid. The focus here is on for-hire truck operators, with the majority of the over 30,000 respondents using tractor-trailers. Driver and fuel costs between them make up 34% + 38% = 72% of these average operating costs: although these percentages fluctuate with changes in fuel prices in particular. Further disaggregation of the sample into truckload (TL), specialized[21], and less than truckload (LTL) business suggests operating costs of $73.2, $74 and $63.2 per hour respectively. Based on what it admits are highly uncertain estimates, the US DOT (Belenky, 2011) puts truck driver time costs at between $19.8/hour and $29.6/hour, but is reticent about offering this figure as guidance. This range is roughly consistent with the above referenced ATRI study, which reports a 2014 average/hour driver wage plus benefits costs of $18.46 +$5.15 = $23.61 /hour. Other recent studies reviewed as part of the present project (Southworth, 2016) produce similar valuations, depending on whether cost components such as fuel are included as time-relevant costs, and whether other vehicle operating costs are included directly, as a marginal per mile or per hour operating cost, or are represented on the basis of depreciation in the lifetime value of vehicle fleet assets.

Just how costly such truck pickup or arrival delays turn out to be will depend on the tightness of the schedules involved, and on the costs of paying for unproductive labor hours. This leads to the question: how exactly does a shipper, receiver, or trucking firm make use of any time saved on a delivery? Can a carrier or private shipper leverage its vehicle and driver assets to obtain more business, and how much time saved is needed to noticeably affect this outcome? As Bone et al (2013) point out, whether there is any effective time saving in the first place will also depend on the extent to which a travel time delay is buffered by time spent in the warehouse, both after production and

[21] This includes "flatbed trailers, tank trucks and agricultural-based carriers as well as carriers dedicated to hauling government munitions, radioactive waste and carriers utilizing specially permitted oversize/overweight loads".

before use at the receiver end of the trip. The impacts will be heavily industry and commodity dependent. Many bulk commodity shipments appear to have limited delay impacts, while delay costs can be substantial in receiving industries where disruptions to just-in-time parts deliveries lead to hold-ups in production line processes.

Focusing on the time-based components of such vehicle operating costs, the US DOT's Highway Economic Requirements System-State Version (HERS, see FHWA, 2005b) estimates "user travel time costs" based on the following five factors:

- Travel time cost in dollars per truck driver hour
- Hourly vehicle depreciation costs
- Hourly cargo inventory carrying costs
- Average vehicle occupancy, and
- The ratio of the value of incident delay to the value of travel time

Here the average vehicle occupancy allows for some shipments to be supported by an additional worker besides the truck driver, and the last entry, when greater than one, "*exacts an additional travel time penalty when traffic is slowed due to crashes.*" (See discussion of on-time reliability below).

Miao et al (2011) updated the estimates based on this HERS-ST approach to obtain the values shown in Table 5.1.

Table 5.1 Value of One Hour of Truck Travel Time

(Source: Miao et al, 2011, see page 12)

	6-Tire Truck	3 to 4-Axle Truck	4-Axle Comb.	5-Axle Comb.
$ Per Person (Driver) Cost	$23.76	$23.76	$23.76	$23.76
Vehicle Operation (Depreciation) Cost	$3.55	$9.59	$8.58	$8.25
Inventory Carrying Cost	-	-	$0.76	$0.76
Average Time Cost per Vehicle Hour	$28.50	$33.35	$35.95	$35.62
Average Vehicle Occupancy	1.05	1	1.12	1.12

The per hour labor costs in this table are slightly lower than the average of $24.44/hour derived by the ATRI study for 2011, but have vehicle depreciation and inventory carrying costs added to them (see below).[22] The HERS-ST model defines "vehicle operation (depreciation) costs" here as a combination of age related and use related vehicle depreciation. Age related costs, which account for

[22] These driver costs were 36% of the ATRI 2011 cost per hour estimates. Multiplying by a factor of (1/0.36) in order to add fuel, insurance and licenses, tires and other repair and maintenance costs to these HERS estimates, based on ATRI derived cost shares, and then adding the vehicle depreciation and inventory carrying costs from the table above produces truck freight operating costs on the order of $69.5 to $75/hour (versus an ATRI estimate of $68.21/hour for what are termed marginal truck operating costs) for 2011.

between 77% and 86 % of the per hour vehicle operating costs shown in Table 5.1, are based on a vehicle's retail purchase price minus salvage value, divided by the number of years in operation, translated into an hourly cost based on average hours in operation per year. Use related depreciation costs are based on lost vehicle performance costs per mile, also converted to a per hour cost, and subtracted from overall depreciation costs to obtain time-related depreciation only (FHWA, 2005b, page 5-49). Inventory carrying costs are taken to be negligible for all but combination trucks (which are, however, those likely to engage in longer trips).

Also based on the methods used by HERS, Kittelson and Associates Inc. (2013, Appendix B) report similar (2008 adjusted) FVOT estimates, suggesting the following representative FVOT values:

- Light (single unit or 6-tire) Trucks = $30/Hour, with a range of values (for sensitivity analysis) of $30/hour to $55/hour;
- Medium (3- and 4- axle) Trucks= $50/hour, with a range of $40/hour to $75/hour
- Heavy (4-axle and 5-axle combination) Trucks = $60, with a range of $40/hour to $80/hour

Similar, but not identical, FVOTs have been used in a number of recent freight planning studies (Southworth, 2016).

Costs of Travel Time Unreliability: Recognizing that a good deal of unproductive labor and also equipment idle time, and hence additional business logistics costs, can be associated with poor or missed pickup and drop windows, a number of studies have expanded the idea of "transportation costs" to include cargo processing and handling costs at either end of a trip. For example, we might consider including the time required to load and subsequently unload a vehicle at both source and destination locations respectively. In doing so, and especially where truck trips start or end at highly congested terminal or port facilities, it is important to know how much "dwell time" is both typical, and also acceptable, at either end of a delivery: and also who suffers most from any (either expected or unanticipated) delays. According to Gong et al (2012, page 13), for example, late vehicle arrivals can result in some or all of the following operational impacts:

- Additional fuel, oil, and truck operation costs,
- Extra in-transit inventory holding costs,
- Interrupted work flows at unloading bays,
- A disturbed production schedule and lower productivity,
- Dissatisfied customers and potential lost sales,
- A large volume of on-site safety stock and high inventory holding costs.
- Potential loss of the opportunity to consolidate multiple outbound shipments, and
- Lost business markets and reduced agglomeration economies

Recent empirical evidence suggests that such dwell times often lead to significant carrier-imposed freight rate increases, with rate increases in the southeastern United States on the order of $24 to $60 for truck dwell times at the destination of from 2 to 5 hours respectively (C.H. Robinson Worldwide Inc., 2015).[23]

The challenge for public agency planners is to find a way to represent this unreliability in vehicle arrival time requirements in a statistically relevant manner, despite having limited access to data sources that capture actual arrival time performance. The principal means of doing this to date has been to use trip time variability, by the hour or by the day, as a surrogate measure for on-time service reliability. van Lint et al (2008) identify four general approaches to using vehicle travel time data to quantify on-time reliability, whether applied to truck or passenger vehicle trips, termed statistical range methods (notably measures of trip time variance or standard deviation), buffer time methods (the extra time needed to ensure on-time arrivals) , "tardy-trip'' measures (such as the "misery index" which compares the average travel time taken over all reported trips, with the average of the worst 20% of trip times), and probabilistic measures (such as the probability that a trip can be made successfully within a specified interval of time). They point out *the potential for considerable inconsistency* between these different measures when applied to the same dataset.

Having chosen one or more of the above methods, the public agency planner then needs a way to assign a monetary value to such time-based (FVOTR) reliability measures. This proves more challenging than deriving a value for FVOT. The most commonly cited method involves merging the factor based method with the freight demand model-based willingness-to-pay approach. This is usually accomplished via a survey-based sample of revealed and/or stated preference responses from freight agents, in which alternative trip characteristics are ranked or otherwise weighted by the respondents. These responses are then used to calibrate discrete choice demand models to estimate the trade-offs between various measures of monetary cost savings or losses, and time based cost factors, as each of these factors affects the choice of vehicle types, modes, destinations, and transport routes (see Section 5.3 below). FVOTR values have been obtained by putting a value on the standard deviation of time by getting respondents to weight trip duration per se versus trip time variation: while another approach has been to elicit the value to freight agents of reducing the percentage of late shipments by a given amount (e.g. by 10%). In a practical application of this approach to benefit-cost analysis, ICF/HLB/LBG (2001, page 66) state that:

"The most significant attributes of shipments after highway improvement are average travel time and travel time variability. Although these can be treated separately, an alternative approach could be to combine them with a percentile value expressed as the mean travel time plus a fixed number of standard deviations. This way, the two measures merge into one. The meaning of this new measure is that x percent of all trips can be achieved within the new time metric."

Taking a similar approach, Alstadt and Weisbrod (2008) suggest that travel time unreliability has the

[23] It was also noted that a desire to keep its drivers generating income from additional movement activity is sometimes seen as more important to a carrier than keeping a shipper as a customer. And the carrier may also wish to keep its drivers happy by favoring shippers who keep vehicle dwell times down: with driver retention a major trucking industry concern at the present time within the U.S. (see ATRI, 2014).

effect of scaling in-vehicle travel time to account for travel time “buffers”, where the buffer generally increases as level-of-service deteriorates. They make use of this idea by scaling their value of travel time (FVOT) estimate as follows:

$$FVOT+ = FVOT*(1+BTI) \tag{5.1}$$

where BTI here is the often referenced “buffer-time-index,” which in their case reflects the additional time, computed as a fraction of the mean travel time, necessary to complete a trip on-time for 19 out of every 20 days. This sort of measure, useful for economic impact studies, makes good use of existing data on highway speeds, now possible using GPS or other highway speed capturing data, sometimes combined with repeated application of model-simulated truck movements to measure the variation in over-the-highway ‘door-to-door’ trip times (see, for example, Cambridge Systematics Inc. et al, 2008; FHWA, 2010; ITF/SHRP2, 2011). It also relies on a single value for FVOT, without needing to derive a separate valuation for FVOTR.

Exploring the idea of deriving a value of travel time reliability without recourse to expensive and hard to generalize freight agent-based surveys, Kittelson and Associates Inc. (2013, 2014) describe a method for estimating the value of reliability based on Options Theory: a method used in financial economics to convert a measure of uncertainty into a certainty-equivalent value, following the work of Pozdena. A benefit of this approach on a highway facility-specific basis is its use of readily available traffic data. A limitation of the approach is that it is inappropriate where variability (of travel times or speeds) cannot be categorized by a suitable statistical distribution. The approach relies on a lognormal distribution of time variability in the case of recurring congestion events, with a separate treatment of comparatively rare but highly disruptive traffic disruption events requiring a suitably determined extreme value distribution (see Appendices B and C of Kittelson and Associates Inc. 2013, respectively). The Transportation Research Board’s SHRP2 reports by Kittelson and Associates Inc. provide detailed formulas and numerical examples of this approach. The statistical complexity of the approach has limited its application to date. However, the approach was used as follows by the Puget Sound Regional Council, as a means of adding the cost of travel time uncertainty in the form of a (freeway-based) “unreliability penalty” to its benefit-cost methodology for the Seattle region (PSRC, 2010, page 19):

$$t = t0 + t0*a*(Vol/Cap)^{b} + U(t) \tag{5.2}$$

where,

t = vehicle delay under conditions of uncertainty, in minutes per mile

t0 = free flow time in minutes per mile

Vol = total link volume in passenger car equivalents (pce)

Cap = total link capacity, also in pce

a,b = model parameters, U(t) = the certainty-equivalent delay penalty (in minutes/mile) from unreliability at travel time t, using the popular Bureau Public Road function to estimate the effects of congestion, represented by the (Vol/Cap) ratio, on vehicle travel time; and where the reliability term U(t) is a polynomial function of this time t. (i.e. $U(t) = c+e*t+f*t^2\ g*t^{2\,+}\ h*t^4$). Data for estimating model parameters consisted of 5-minute interval highway speeds collected at several locations for hundreds of time periods, from which the mean and lowest 1% of speeds were used to quantify a freeway unreliability penalty. Extending this approach to capture non-freeway roads is required if the variability in multiple origin-destination, door-to-door freight shipments is to be obtained for regionwide or corridor studies such as the one researched in this report.

Gong et al (2012) provide one of the few U.S. examples of using inventory theory directly to estimate the costs of delay *to shippers* who also operate as receivers of freight. In the process they shed light on the range of value of time costs we might expect across different industry/commodity groups. Based on four hypothetical case studies, each based on different types of services (termed event-oriented and quantity oriented stock-outs), and different levels of randomization in customer demand and lead time (i.e. the time from the ordering decision until the ordered amount of product is available on the shelf), they estimate both FVOTs and FVOTRs for nine industry-based commodity groupings (Food, Chemical, Pharmaceuticals, Auto, Paper, Electronics, Clothing, Other Manufacturing, and Merchandise). Their estimates range from an average low value across all four hypothetical test cases of $0.53 for a one hour delay per truckload for general merchandise freight, to a high of just under $13.9 for a one hour delivery delay in the chemical industry; while random variation in such delays has an average cost of $31.04/hour for chemical truckload deliveries, versus a value of $2.2/hour for generalized merchandise deliveries, based on simulated in-transit time standard deviations.[24] The resulting (un)reliability costs fall between 1.8 and 4.2 times the mean per hour late arrival costs.

In summary, while recent studies based on the Cost Factor Method yield similar dollar values for the various components of truck operating costs, notably labor and vehicle depreciation costs, there is as yet no consensus on a) whether to include the fixed costs of transport equipment utilization, fuel consumption, or cargo carrying costs as part of over-the-road transportation costs, b) whether to extend the cost impacts of longer travel times to capture other pre- and/or post-transit labor, inventory management or other freight-relevant logistics costs, and c) how best to put a monetary value of travel time unreliability. There is also the issue of non-linearity in the valuation of time saved or lost. For example, is a 10 minute savings worth the same, more, or less per minute when associated with a 3 hour trip versus a 30 minute trip? The econometric modeling approach described below, based on freight agent responses to questions about either actual or analyst-conceived alternative freight transportation options offers one approach for addressing these issues.

***5.2.2.2 Demand Model-Based "Willingness-To-Pay" Methods*:** In this approach the value of travel time is estimated as the marginal rate of substitution between money and time (at a constant level of utility) based on the parameter values obtained from a discrete choice freight demand model. A significant number of different variables have been found to affect both travel time and travel time

[24] With transportation costs estimated on the basis of a freight rate formula derived by Tyworth and Zeng (1998), the inclusion of fuel costs in such rates is arguably implied.

reliability valuations that these models produce (see, for example, Small et al, 1999; Feo-Valero et al, 2011; Gong et al, 2012; Rotaris et al, 2012; Bone et al, 2013). These include:

- trip distance – local versus regional deliveries, versus long-haul, including inter-state shipments;
- temporal (time of day, also seasonal) context; for example, if higher driver labor costs are associated with overtime or traditional holiday times;
- the contractual arrangement under which the freight is delivered (including the use of shipper owned versus for-hire carriage, who is responsible for the freight when in transit, and how the carrier and driver are being paid - by the mile or by other methods[25]);
- vehicle type, size and load factor; shipment value, size and type of packaging required (e.g. bulk, break bulk, packaged versus loose goods, palletized, refrigerated, containerized);
- the nature of, and stage of movement within the commodity/industry product supply chain (e.g. moving raw materials, semi- or fully manufactured parts, or wholesale or retail finished products);
- whether for domestic consumption or import/export;
- whether the goods shipped are customized or manufactured to order, versus delivered on a regular replenishment of stock interval;
- the scheduling flexibility based on the needs of the shipper or receiver of the freight;
- the market value of the commodity being shipped; and
- the presence and level of traffic congestion, of both a recurring and unexpected nature

Ideally, all of these variables should be accounted for at the same time. In practice, and due principally to the limited size of past data samples, this has proved very difficult to achieve. In selecting a set of FVOT measures for project purposes it seems prudent to try a range of valuations based on one or more of these variables, and then examine the consistency in the estimates of corridor time costs produced. The most popular approach to estimating mode, route, or destination choices to date has been based on linear additive forms of generalized travel cost function that tie time costs to monetary ones. For example:

$$\text{Transportation Cost} = \alpha 1 * \text{Money Cost} + \alpha 2 * \text{Travel Time} + \alpha 3 * \text{Travel Time Reliability} \quad (5.3)$$

where $\alpha 1$, $\alpha 2$ and $\alpha 3$ are model parameters to be estimated, and where dividing all right hand side cost terms by $\alpha 1$ produces a dollar-valued generalized cost. The ratio of $\alpha 2/\alpha 1$ produces a frequently used estimate of the value of travel time. Similarly, dividing $\alpha 3$ by $\alpha 1$ transforms time variability into a time reliability-based travel cost, and dividing $\alpha 3$ by $\alpha 2$ produces what has been termed a "reliability ratio", or RR, which is taken to represent the relative importance of on-time arrival reliability to expected shipment travel time.

[25] Most over-the-road or long-haul truck drivers are paid on a per-mile basis while LTL pickup-and -drop drivers are generally paid by the hour (Torrey and Murray, 2015, page 24).

The Travel Time Reliability term in equation (5.3) has taken a number of forms in past studies. The most common approach is to equate it with the standard deviation of travel time. Batley et al (2008) provide details of the mathematical derivation of this RR approach, and the use of standard deviation instead of travel time variance. They also show an equivalence between this general "mean-variance" approach to trip on-time unreliability, and one based on measures that more directly associate additional transport costs with earlier-than-scheduled, as well as later-than-scheduled shipment arrivals. For example:

Transportation Cost = $\alpha 1$* Money Cost + $\alpha 2$* Schedule Delay Early + $\alpha 3$* Schedule Delay Late + δ*Late (5.4)

where Schedule Delay Early and Late are both measured as the time difference between a preferred and an actual vehicle arrival time; and where 'Late' is a dummy variable set to unity if Schedule Delay Late > 0, and to zero otherwise, interpretable as a discrete lateness penalty (see also Small et al, 1999).

As a practical matter, the approach represented by equation (5.3) proves relatively easy to implement within planning studies such as the one undertaken in the present project once a suitable shipper/carrier/receiver or mixed freight agent demand model has been calibrated. In contrast, an approach based on equation (5.4), while conceptually more appealing, is difficult to implement since it requires freight agent cooperation in reporting actual vehicle scheduling problems encountered. Recognizing the importance of travel duration or distance to such results, Gong et al (2012) suggest an alternative to equation (5.3). Their trip cost function can be stated as:

Transportation Cost = $\alpha 1$* Monetary Payment + $\alpha 2$* PD (5.5)

where Monetary Payment refers here to a hypothetical toll value, and where PD = percentage delay, measured as the travel time in excess of congestion-free travel time. A value of $0.352 per percentage delay was estimated, as a surrogate for travel time reliability. Using this value, a 30-minute delay on a 1 hour trip results in a PD = 50, and an approximate cost of unreliable on-time arrival delay of $0.352*50 = $17.6 per 30 minutes, which equals $35.2/hour. In contrast, a 30 minute delay to a 5 hour trip would produce a PD of 10 (%), leading to value of delay equal to just under $0.3/hour.

The empirical findings from a number of additional FVOT and FVOTR studies are reported in the Southworth (2016), including both U.S and foreign (principally European) studies, also capturing the results of a number or recent review articles on the topic. Significant weaknesses in the current state-of-the-art include a lack of consensus about how to disaggregate value of time studies to capture the obviously wide range of situation and commodity specific values involved, as well a lack of consensus on the specific set of travel time-impacting cost elements to include for the purposes of cost-benefit analysis. Looked at more broadly, future studies are likely to require a better linkage between the types of industries and the commodities being transported, and the types of supply chains they operate within, if the role and significance of transportation service quality (notably reliability, as well as cost) is to be quantified appropriately. As more is learned about how supply chains both work and influence transportation decisions, more elaborate modeling efforts seem likely. The work of the Boston Logistics Group, reported in CSI et al (2006), offers some useful insights here towards a practical approach to what is a complex cause-and-effect problem. This includes their (relatively high level) categorization of freight shippers based on production strategy, transportation mode, order trigger mechanism and breadth of coverage between raw material supplier and final consumer: leading to shippers being placed into one of six broad types: extraction, process, discrete, or design-to-order manufacturing, distribution, or reselling - each with different implications for how a company invests in and subsequently benefits from transportation cost (including time) savings.

5.3 Example Empirical Study

5.3.1 Delay Impacts on Truck Operating Costs: A Factor-Based Method

Using a modification of the factor-cost based method for assessing vehicle movement costs, the truck class-specific trip cost equations described in Chapter 4 (equations 4.1 and 4.2) were used to route the O-D specific commodity tonnages described in Chapter 3 over the national highway network. These costs, which include driver labor, fuel consumption, and vehicle operation and maintenance costs, are referred to below as vehicle operating costs.

Congestion impacts on truck operating costs along the I-85 corridor were estimated on the basis of the difference in travel times with and without traffic congestion, i.e. on the differences in congestion-inclusive travel times derived from the mixed passenger plus truck assignment model, and travel times based on a free-flow traffic assignment in which trucks take the least cost routing under "ideal" non-congested conditions: with this time difference converted into vehicle operating costs (OC) (cf equation 4.1), and multiplied by the number of daily truck trips using I-85/I-285 to complete their deliveries, i.e.

$$\text{Delay Cost} = \sum_i \sum_j \sum_v \text{Trips}(v,i,j) * [\text{Assignment Model OC}(v,i,j) - \text{Free Flow OC}(v,i,j)] \qquad (5.6)$$

Table 5.2 summarizes the results.[26] Note that the truck trips referred to here are based on the disaggregated FAF3 interregional totals for the corridor, and the resulting vehicle miles of travel (VMT) and travel delay costs in this table are based on complete O-to-D goods movements over the national highway network, whether within or outside Georgia. That is, while Interstate 85 within Georgia is the corridor of interest from the viewpoint of defining all relevant O-D-commodity flows, many of these flows , notably the Internal-to-External and External-to-Internal to the Georgia flows, include a majority of miles traveled on highways other than I-85 or I-285 around Atlanta (e.g. a trip

[26] Combination semi-trailer and combination double results are summed into one category here, although results for each vehicle class were derived separately during the modeling exercises.

from Chicago, IL to Miami, FL). Taken across the corridor as a whole, that is, weighting these O-to-D trip time differences by the number of truck trips per O-D, yielded an average free flow truck operating cost of $1.39 per mile, versus a congested, mixed flow cost of $1.47 per mile: or a difference of 8 cents per mile due to over the road congestion. For a truck that travels 120,000 miles a year this implies an annual congestion delay-induced cost of $9,600. Summed over all O-D-V flows assigned to the corridor this yielded an estimate truck daily delay cost of just over $1.25 million, which represents 5.4% of the total daily truck operating and maintenance costs estimated by the model - with the major contributor extra operating hours associated with delays in moving through Atlanta.

Table 5.2 Estimated Daily Truck Operating Delay Costs for O-Ds Using the I-85 Corridor

2007 Estimates	Internal Trips	Internal-External Trips	External-External Trips	All Truck Trips
Single Unit Trucks	7,573	3,560	954	12,087
Truck Trailers	1,488	1,335	481	3,304
Combination Trucks	3,555	11,056	6,780	21,391
Daily Truck Trips	12,617	15,951	8,215	36,784
Daily O&M Costs ($)	1,441,700	10,408,837	11,178,331	23,028,868
Daily Truck VMT*	969,920	7,271,810	7,408,759	15,650,489
Mixed Flow $/Mile**	1.486	1.431	1.509	1.471
Free Flow $/Mile	1.390	1.396	1.373	1.392
Daily Delay Costs ($)***	109,612	350,957	789,524	1,250,092
Delay Costs (Cents/VMT)	9.7	3.5	13.5	8.0

Notes: * VMT includes all O-to-D miles whether within Georgia or not. ** Mixed Flow $/Mile refers to mixed passenger plus freight traffic congestion-based truck operating cost.*** Delay Costs here are over-the-highway truck operating delay costs.

5.3.2 Estimating Travel Time Unreliability Costs

Estimating Travel Time Variability

The effects of travel time unreliability on the flow estimation process was introduced by adding a surrogate for on-time arrival unreliability in the form of a trip time variability-based measure. Given the project's experimental nature and data limitations, and the intra-urban (i.e. within Atlanta) nature of the corridor's major congestion locations, an approach based on the method for computing travel time variability developed by Black, et al (2009) was selected, i.e.

SDt(i,j) (standard deviation of time for i-to-j) = CVt(i,j) * t(i,j)*cong* (5.7)

where,

$CVt(i,j) = \alpha\, CIt(i,j)^{b} * d(i,j)^{g}$ (5.8)

for CVt(i,j) = the coefficient of variation for i-to-j trips = the standard deviation of i-to-j travel time t(i,j) divided by the congestion-model based travel time, t(i,j)*cong* in a time period *t* (which in this study is the travel period simulated in the assignment model); and where:

CIt(i,j) = a congestion index = model estimated congested (*cong*) travel time divided by the free flow (*FF*) travel time, in time period *t*, *i.e.*

$$CIt(i,j) = t(i,j)_{cong} \;/\; t(i,j)_{FF} \tag{5.9}$$

for α = a constant/scale factor (default = 0.16)
b = an elasticity coefficient for *CI* (default = 1.02)
g = an elasticity coefficient for distance (default = -0.39)
and, d(i,j) = distance in kilometers from origin i to destination j.

An additional useful property of this approach, as suggested by the VOT literature review, is the decay in value of the CV, and hence in the value of SD, with additional trip distance.

Assigning a Monetary Cost to Travel Time Variability

Based on the literature review of past value of freight travel time and travel time reliability studies, and the very wide range of valuations reported, it was decided to build a value of time matrix based on the following six factors: industry type, commodity class, commodity value, distance transported, perishability/on-time sensitivity[27] , and a factor termed dominant supply chain (SC) type. This last factor was based on work by the Boston Consulting Group Inc., as reported in CSI, et al (2006), which describes an approach to linking a shipper’s need for, among other things, reliable transportation services via the type of supply chain it engages in. It was used here as one more piece of information to inform the selection of what are the rather broad commodity-specific VOTR weightings shown in Table 5.3. These factors were used to divide the 43 commodities modeled into three value of time reliability categories, labeled low, medium and high in Table 5.3. The subsequent commodity groupings and VOTR valuations are meant to be experimental only. Ideally each of these factors should be weighted to reflect their individual contributions to value of time and time reliability. In the present study a commodity was first placed into one of four VOT Groups. These groups are labeled A B, C, and D in Table 5.3 and are based loosely on five of the six influential factors, with distance traveled and value per ton dominating the rankings. This, rather crude breakdown was used in the empirical tests reported below, although others were experimented with.

An effort was also made to include ideas of perishability and schedule sensitivity in the groupings, and to also recognize the different types of supply chain used in different industries (NAICS classes,

[27] This perishability/time sensitivity category was at best approximated, given the rather broad naturel of the 43 SCTG level 2 commodity classes employed in this study, but may prove important in more detailed or industrial sector /commodity specific studies.

Table 5.3 Travel Time Reliability Factors: Example Commodity Groupings

NAICS	SCTG	Commodity	Corridor $/Ton	VOTGroup	Distance 1	Distance 2	Distance 3
115	1	Live animals/fish	4,340	A	High	High	High
111	5	Meat/seafood	2,565	A	High	High	High
339	38	Precision instruments	39,316	A	Medium	High	High
312	9	Tobacco prods.	39,076	A	Medium	High	High
325	21	Pharmaceuticals	18,739	A	Medium	High	High
334	35	Electronics	11,089	A	Medium	High	High
336	37	Transport equip.	10,176	A	Medium	High	High
333	34	Machinery	8,630	A	Medium	High	High
315	30	Textiles/leather	7,374	A	Medium	High	High
336	36	Motorized vehicles	5,933	A	Medium	High	High
337	39	Furniture	4,547	A	Medium	High	High
312	7	Other foodstuffs	1,403	A	Medium	High	High
421	40	Misc. mfg. prods.	6,937	B	Medium	Medium	High
323	29	Printed prods.	3,919	B	Medium	Medium	Medium
422	43	Mixed freight	3,858	B	Medium	Medium	Medium
325	23	Chemical prods.	3,417	B	Medium	Medium	Medium
332	33	Articles-base metal	2,805	B	Medium	Medium	Medium
326	24	Plastics/rubber	2,691	B	Medium	Medium	Medium
322	28	Paper articles	1,892	B	Medium	Medium	Medium
331	32	Base metals	1,448	B	Medium	Medium	Medium
111	6	Milled grain prods.	1,230	B	Medium	Medium	Medium
326	31	Nonmetal min. prods.	1,154	B	Medium	Medium	Medium
312	8	Alcoholic beverages	1,123	B	Medium	Medium	Medium
325	20	Basic chemicals	1,075	B	Medium	Medium	Medium
322	27	Newsprint/paper	969	B	Medium	Medium	Medium
999	99	Unknown	480	C	Medium	Medium	Medium
321	26	Wood prods.	706	C	Low	Low	Low
212	10	Building stone	630	C	Low	Low	Low
324	18	Fuel oils	603	C	Low	Low	Low
111	4	Animal feed	592	C	Low	Low	Low
324	17	Gasoline	560	C	Low	Low	Low
111	3	Other ag prods.	540	C	Low	Low	Low
213	16	Crude petroleum	452	D	Low	Low	Low
562	41	Waste/scrap	387	D	Low	Low	Low
111	2	Cereal grains	375	D	Low	Low	Low
324	19	Coal-n.e.c.	352	D	Low	Low	Low
212	11	Natural sands	338	D	Low	Low	Low
325	22	Fertilizers	329	D	Low	Low	Low
212	14	Metallic ores	287	D	Low	Low	Low
321	25	Logs	242	D	Low	Low	Low
212	13	Nonmetallic minerals	214	D	Low	Low	Low
212	12	Gravel	86	D	Low	Low	Low
212	15	Coal	56	D	Low	Low	Low

shown along with best fit SCTG classes down the left hand side of in Table 5.3). Distance effects were made more explicit, given the O-D specific nature of the dataset, leading to a partitioning into the three distance classes show in the table. Distance 3 trips included Internal to the south-eastern region trips under 100 miles in length, while Distance 2 trips included all other south-east regional trips, and Distance 1 trips included the generally much longer external and inter-external (to the south-east region) O-D trips modeled. Using these commodity and distance based groupings, a set of reliability ratios (RRs) was applied to the O-D-Commodity modeled flows. For example, a "High" VOTR rating of 3.12, a "Medium" rating of 1.6, and a "Low" rating of 0.0 (i.e. no significant effect due to late, or early, arrivals) was experimented with. These values are multiplied by the standard deviation of travel time estimated for each O-D –Commodity flow ($SD_{t_{OD}}$) ,as computed by equations (5.7) –(5.9) above, and multiplied by the value of one hour's worth of trip operating cost for that O-D movement (which depends in turn on the mix of truck size classes and body types used). Given the many different parameters involved in this (and the other parts of) this modeling process, sensitivity analysis was be performed to gauge the effects of each parameter value. The following are example results for a specific set of VOT and RR parameters.

Example Model Results

Table 5.4 shows a set of example model travel time variability (TTV) induced costs, based on four different sets of FVOTR values.

Table 5.4 Example Estimates of the Costs of Trip Pickup or Delivery Time Unreliability

A) FVOTR=3.12	**External to GA Trips**	**GA Int.-Ext. Trips**	**GA Internal Trips**	**All Trips**
DailyTruck O&M + TTV Costs	11,032,092	11,072,365	1,558,963	23,663,420
Daily TTV Costs	210,327	306,962	117,264	634,552
% Costs Due to TTV	**1.91%**	**2.77%**	**7.52%**	**2.68%**
B) FOVTR = 2.0	**External to GA Trips**	**GA Int.-Ext. Trips**	**GA Internal Trips**	**All Trips**
DailyTruck O&M + TTV Costs	10,997,128	10,999,259	1,516,869	23,513,256
Daily TTV Costs	175,364	233,856	75,169	484,389
% Costs Due to TTV	**1.59%**	**2.13%**	**4.96%**	**2.06%**
C) FVOTR=1.6	**External to GA Trips**	**GA Int.-Ext. Trips**	**GA Internal Trips**	**All Trips**
DailyTruck O&M + TTV Costs	10,984,642	10,973,150	1,501,835	23,459,626
Daily TTV Costs	162,877	207,747	60,135	430,759
% Costs Due to TTV	**1.48%**	**1.89%**	**4.00%**	**1.84%**
D) VOT Group Based FVOTRs	**External to GA Trips**	**GA Int.-Ext. Trips**	**GA Internal Trips**	**All Trips**
DailyTruck O&M + TTV Costs	10,965,757	10,932,020	1,473,069	23,370,846
Daily TTV Costs	143,992	166,617	31,369	341,978
% Costs Due to TTV	**1.31%**	**1.52%**	**2.13%**	**1.46%**

The first two sets acted as “benchmark” results (among a number tested), using a single Freight Value of Travel Time Reliability across all 43 SCTG commodity classes and distance intervals. Run A uses an FVOTR of 3.12 (for example, for an implied Freight VOT = 0.8 times the vehicle operating cost and a Reliability Ratio (RRR) of 3.9, (i.e. 0.8 x 3.9 =3.12). Run B as assumes a much lower across the board FVOTR of 2.0 (e.g. an FVOT of 1.0 x an RR of 2.0). Run C assumes an across the board FVOTR of 1.6 (e.g. an FVOT of 0.8 x an RR of 2.0). Finally, Run D uses the range of FVOTRs implied by Commodity-based VOT Groups and Distance Classes shown Table 5.3. In this scenario a High value refers to an FVOTR of 3.12, a Medium value to an FVOTR of different 1.6, and a Low value to an FVOTR of zero (i.e. not important to that commodity class – mainly low valued, bulk commodities). The results are again broken down geographically, showing the values obtained for flows entirely within, with an origin or destination in, or using I-85 to pass through the state of Georgia. Run D proves to be the most conservative and demonstrates the importance of distinguishing between commodity-class specific FVOT and RR values –versus Runs A, B and C which do not differentiate in this manner.

The resulting, congestion-induced trip time unreliability costs in the table represent between 1.3% and 2.7% of overall (i.e. operating plus travel time variability) delay costs, even as early as calendar year 2007, when congestion on the corridor’s Interstate highway was heavily localized around a few locations within the Atlanta metropolitan area: notably where the I-285 circular meet up with other major Interstates and passed close to heavy concentrations of freight-generating industry whose access to the corridor is clearly important to their day-to-day business. The most impacted trips under this heavily distance-influenced set of model scenarios are the within Georgia trips local to (within 100 miles of) the corridor, where a 2.1% to 7.5% impact was estimated. While clearly assumption-specific, this result again shows the potential for considerable variability within such results, and therefore the need to carefully define the model parameters used. Even the most conservative of the three model simulations, Run D produces a delay equivalent to some $340,000 per day in 2007. When added to the $1.25 million cost of delay reported in Table 5.2 above, this implies a daily cost of congestion to the trucking industry (and by implication to its customers) of around $1.6 million dollars: or an annual cost to trucks making use of the corridor for some portion of their trips of $580 million. Combining the estimated extra travel time costs with those estimated for travel time unreliability (variability), the four scenarios shown in Table 5.4 yield an estimated congestion-induced costs of between 7% and 8.2% of the free-flow, uncongested truck operating costs for trucks using I-85 for part of their travel through Georgia.

5.4 Some Conclusions for Planning Study Applications

1. For the purpose of valuing travel time savings or delays in highway corridor planning, a review of the empirical evidence indicates that both trip time duration and on-time arrival reliability are important cost determinants, and that each can vary *a great deal* depending upon a number of factors. These include the sensitivity of the freight agents involved to late vehicle arrival times (for pickups as well as deliveries), the nature of the commodity shipped, shipment distance and trip duration, the

type of vehicle used, the type of contractual arrangements involved, and the nature and extent to which traffic-related delays themselves are present.

Figure 5.1 summarizes how each of these six factors have been shown, in the above reviewed literature, to impact one or more time-related costs associated with vehicle operation, cargo carrying, driver and other labor and asset utilization and depreciation costs. For example, and testifying to its demanding data requirements, the importance of "On-Time Sensitivity" to truck arrivals depends on at least five different factors: the originating and receiving industries' needs for, and cost savings associated with, tight time window-based operations; the type of commodity shipped (e.g. perishable, highly valued and/or highly customized goods); the distance transported and level of network congestion, both of which can make it harder to get a truck to arrive on time; and the nature of the contractual arrangements governing who carries the freight, including who pays, and how they pay (e.g. per hour or per vehicle mile) for any delays in shipment arrival.

2. Shippers and receivers of freight are likely to put different valuations on time delay-related costs than carriers such as trucking firms. It is the shipper's value of time saving and reliability of delivery that is most likely to reflect economic value, whereas the trucking firm's perceptions of delays will be reflective of the costs of vehicle and driver time and schedule adherence in support of more efficient asset utilization (Bone et al, 2013).

3. While cargo carrying (= in-transit inventory) costs for most truck trips are comparatively small, unless going very long distances, inventory holding and dwell time practices at both ends of a trip can be significant. This implies the need to include these additional freight logistics costs in the economic costs due to over-the-highway delays, especially those on an unanticipated and prolonged nature. The effects of these delays on future trucking activity will then depend also on who (shipper, carrier, receiver, broker) bears these extra business costs.

4. Differentiating truck movements, and freight movements in general, on the basis of significant differences in value of time and on-time reliability is both conceptually complex and challenging in its data requirements. While past studies support the contention by Weisbrod (2008) that:

”*Appropriate scaling of the value of time in a commodity specific framework is of particular importance when examining the impacts of reliability changes on freight dependent industries.”*

There is no consensus as yet on how to rank commodities, or industries, on the basis of value of time, other than a broad appreciation that assigns a comparatively high value to perishable goods and to goods used in just-in-time and custom ordered manufacturing or on-demand retailing. Much lower FVOTs seem to be appropriate for most bulk or raw material transports. Shipments of chemical products and other semi- or fully manufactured and containerized goods tend to fall somewhere between these two extremes. Service industry goods have received little study to date.

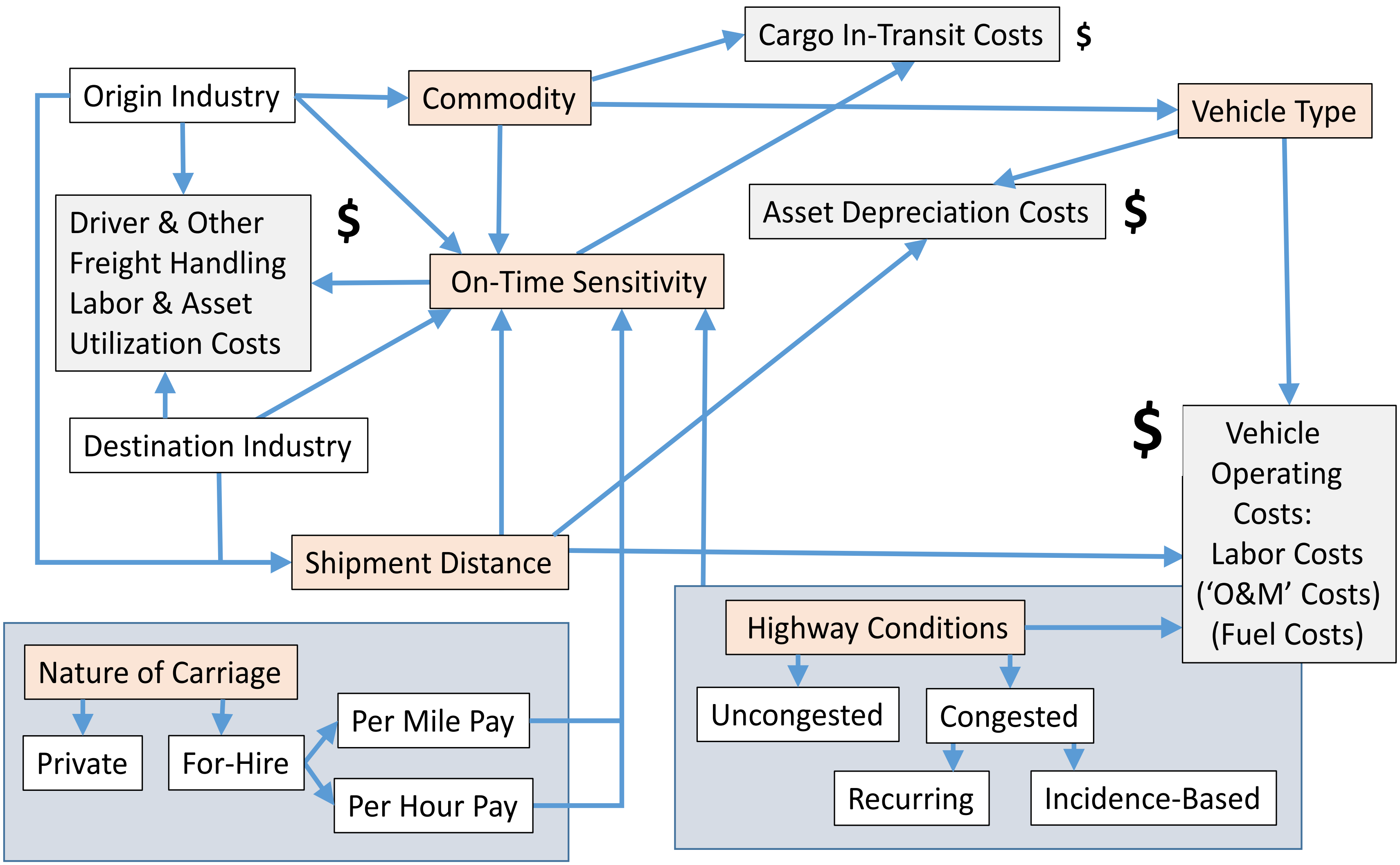

Figure 5.1 Some Factors Affecting the Valuation of Freight Travel Time and Its Disaggregation for Planning Studies

5. Currently, the easiest way to introduce travel time unreliability into planning models is to equate it with a weighted version of shipment time variability. In past studies this weighting process has used linear transportation cost functions that incorporate monetary costs, trip times, and the standard deviation of trip time (which keeps each cost component in dollar terms), with weights derived within logit or other forms of discrete choice freight demand model. The most popular method for calibrating such models is to use freight agent/agency responses derived from stated preference surveys, or combined stated preference/revealed preference data collection methods. To date, these studies have produced a wide range of FVOT and FVOTR estimates, based on limited sample sizes and hard to generalize industry/commodity and geographic context specific conditions. The non-linear, trip distance and duration impacted nature of recent travel demand studies suggests further attention to disaggregation of time delay or savings impacts for both forecasting and cost-benefit analysis purposes.

6. Some of the more technically advanced freight demand modeling studies suggests that freight agent responses to either lost or saved travel time are non-linear, with different valuations suited to both very small and also very protracted trip durations, and in some instances to early as well as late arrival of pickup or delivery vehicles. Just as troubling, if not more so, is the problem of both obtaining and quantifying the differential impacts of specific components of time costs on the decision-making behavior of freight shippers, carriers, and receivers.

7. Whatever the methodology used, larger sample datasets are needed in order to gain confidence in the differences in FVOT and FVOTR values that have been reported across different industries/commodities, shipment distances and durations, types of carriage, and anticipated levels of highway network performance.

8. Finally, given the state of the empirical evidence from past studies, as well as the continued uncertainty over the conceptual basis for deriving such savings, dollar values assigned to specific travel time savings or losses should be treated as approximations when applied within freight planning studies that lack suitably representative, study area specific information on shipper and/or carrier and/or receiver responses to movement delays. Future studies are likely to require a better linkage between the types of industries and the commodities being transported and the types of supply chains they operate within, if the role and significance of transportation service quality (notably reliability, as well as cost) is to be quantified appropriately. As more is learned about how supply chains both work and influence transportation decisions, more elaborate modeling efforts can be undertaken. A practical, cost-sensible data-collection approach to this problem represents a challenging but potentially lucrative area for future study.

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