NCDOT HWY 2006-09

NC Truck Network Model Development Research

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Abstract

This research develops a validated prototype truck traffic network model for North Carolina. The model includes all counties and metropolitan areas of North Carolina and major economic areas throughout the U.S. Geographic boundaries, population and employment define the study areas. The network is based on the National Highway Planning Network and it includes Interstates, US Highways, and secondary roads. The North Carolina network attributes include highway type, speed, and terrain. The base year long haul truck data is based on FHWA Freight Analysis Forecasting origin-destination data for North Carolina including origins and destinations outside North Carolina. Short haul traffic and back haul truck traffic are generated using simplified trip generations rates and adjustments to the FAF data. Base year 2006 truck traffic estimates for North Carolina are validated by over 450 truck traffic counts throughout the state. Only ADTT (average daily truck traffic) is estimated by the network model, not total vehicle traffic including automobiles. Since the model does not include automobile trips and truck-only traffic is usually far below roadway capacity, the current network model is not built with a capacity-constrained traffic assignment feature. The network is sensitive to input speed but not to traffic volumes on the highway. Consequently any network changes for scenario testing have to be expressed in terms of speed changes to the network links affected.

Key Words Truck network model, transportation planning, travel demand modeling	Distribution Statement …leave blank…

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Preface

This report contains the results of the research project NCDOT HWY 2006-09. The report describes the development, data, calibration and validation of a truck network model to estimate truck traffic to, from and within North Carolina. The network includes major and minor highways within North Carolina and major highways to other states in the U.S. Within North Carolina the traffic analysis zones are based on counties and sub-regions of metropolitan areas. As the network extends beyond North Carolina the traffic analysis zones increase from county size at the North Carolina border to economic districts in distant states. The base year for which the model is calibrated is 2006. The data used for model development and calibration mainly include the truck traffic classification count data collected by NCDOT in 2006 and 2007 and the 2002 Vehicle Inventory and Use Survey (VIUS) data. Another important data source is the 2002 Freight Analysis Framework (FAF2) data for North Carolina, which was provided by the USDOT Federal Highway Administration. This data set provides commodity truck flows from, to, and within North Carolina, which were mainly developed from the 2002 Commercial Flow Survey (CFS). Adjustments of the origin-destination data have been made for internal, short-haul, and empty truck trips. The resulting model provides an excellent foundation for future truck modeling and logistics analysis in North Carolina.

Acknowledgements

The NCSU research team recognizes the vision, professionalism, and constant support of Alpesh Patel (NCDOT Transformation Management Team) and Kent Taylor (Head, Traffic Surveys Unit). As project manager Mr. Patel guided this research through the intricacies of NCDOT and identified important contacts and sources of data at FHWA. Kent Taylor and his staff provided hundreds of truck traffic counts that were vital to the successful calibration and validation of the NC truck network model. We also appreciate the contributions of the NCDOT Steering and Implementation Committee: Dr. Judith Corley-Ley, Mike Bruff, Dr. Moy Biswas, Dennis Pipkin, Loretta Barren, Bob Foyle, Stephanie Ayers, Stephen Piotrowski, Shirley Williams, Warren Beatty, Roberto Canales, Pamela Davis, Bill Finger, Joseph Geigle, and Mike Koslosky.

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EXECUTIVE SUMMARY

Background

Trucks are a vital link in the U.S. logistics system for moving domestic and international freight. Trucks have the flexibility to go anywhere there are highways and streets. They travel from dockside to curbside, from factories to stores and homes, from producer to consumer. Trucks carry about twice the tonnage of the other modes combined.

Trucks also have significant impacts on pavement and bridge design and maintenance. As truck traffic and truckloads increase, damage disproportionately increases. Nationally these impacts are significant because U.S. truck traffic has more than doubled in the past 20 years and may double again in the next 20 years according to FHWA estimates. Yet, highway lane miles have increased less than 5 percent. Furthermore, trucks contribute to congestion and emissions. Such issues are especially acute in North Carolina, which has four interstate highways carrying about 13 percent of the total U.S. truck traffic, far more than the average truck traffic of other states. As North Carolina builds or improves more interstate and intrastate mileage (I-26, I-73/74, US 64 and US 17), congestion, infrastructure maintenance, and air quality problems associated with truck traffic will increase. Thus, improved truck forecasting tools are important.

Good truck traffic forecasts support good policy decisions. The anticipated future truck traffic in North Carolina will affect infrastructure decisions involving hundreds of millions of dollars. In North Carolina the current state of the practice is to forecast truck traffic for individual highway projects by applying simple statistical procedures to current and historical truck traffic data. This approach, however, ignores important transportation system and network effects such as traffic diversion to competing routes and modes, inter-modal transfers, interstate versus intrastate truck traffic, and economic development. For proper consideration of alternative statewide highway projects these effects should be simulated with a network model that is analogous to the traditional "four-step" method used for urban travel.

The NC Truck Network Model Project (NCDOT HWY 2006-09)

In July 2005 NCDOT funded NC State University and ITRE to prepare a prototype statewide truck network model to address the aforementioned issues. This report describes that effort and the results.
The primary objectives of the project are:

- To select a model framework that can be used in North Carolina to conduct policy assessments for Strategic Corridors, especially regarding truck traffic.
- To develop the prototype model and validate the model against the base year truck flows.
- To demonstrate the use of the model for policy, systems-level, or project-level decisions.

All objectives have been accomplished. The model (Figure ES - 1) includes all counties and metropolitan areas of North Carolina and major economic areas throughout the U.S. Population and employment distinguish the study areas. The network (Figure ES - 2) is based on the National Highway Planning Network (2005 version) including Interstates, US Highways, and secondary roads. The North Carolina network attributes include highway type, speed, and terrain (coastal, central and mountain regions).

The base year long haul truck data is based on FHWA Freight Analysis Forecasting origin-destination data for North Carolina including origins and destinations outside North Carolina. Truck traffic that is not produced by FAF2 trips is mostly local short haul traffic, which is generated using simplified trip generation rates in the model. Base year 2006 truck traffic estimates (Figure ES - 3) in North Carolina are well validated by about 460 48-hour truck traffic counts throughout the state (Figure ES - 4).

The proposed I-40 Yadkin River bridge replacement project served as a scenario to test the project planning capability of the truck network model. Of concern are the construction impacts and subsequent congestion and truck traffic delay caused by the closing one of the Yadkin River bridge spans and diverting two-way traffic to the remaining two-lane span and a parallel detour route on US 158. Results indicate that the model performed well and that significant congestion will occur.

Limitations of the Model

When using the model there are several limitations that should be observed:

Only ADTT (average daily truck traffic) is estimated for the network model, not total vehicle traffic including automobiles. Since the model does not include automobile trips and truck-only traffic is usually far below roadway capacity, the current network model is not built with a capacity-constrained traffic assignment feature.

The network is sensitive to input speed, not to traffic volumes on the highway. Consequently any network changes for scenario testing have to be expressed in terms of speed changes to the network links affected. Thus, network improvements from adding lanes (capacity) will not make the model estimate different traffic volumes on the highway. The network improvements (or network degradation as in the case of the Yadkin River Bridge) must be accompanied by changes in link speeds.

Long haul truck traffic estimates depend on national estimates produced by the FHWA FAF2 data. Short haul truck traffic in North Carolina is estimated based on employment (0.1 truck trips/employee/day). This total average rate does not recognize individual NAICS categories of employment. The rate is close to the lower end of the rates reported for some U.S. cities. Because the rate is a state average, it does not explicitly reflect intense truck activity such as that experienced at trucking hubs. This limitation is due to the aggregation of truck activity locations into counties and metropolitan areas, as they serve as traffic analysis zones (TAZs) in this model.

Findings and Conclusions

The primary objective of this research - to develop a base year truck network model for North Carolina – was accomplished. The validated truck model was used to:

- Simulate year 2006 truck flows in and across the state,
- Compare the relative magnitudes of North Carolina truck traffic by region (mountains, central, and coastal) and by 12 highway functional classifications including urban and rural interstates, arterials, and local roads,
- Identify the relative size of interstate truck flows from North Carolina to major interstate destinations, and
- Estimate truck traffic impacts on detour routes resulting from highway and bridge work zones.

The model has particular strengths in that it is a statewide model that can be used for:

§ Intercity / inter-region travel forecasting,
§ Rural area travel forecasting,
§ Internal-external travel forecasting for a local North Carolina study area,
§ External-external travel forecasting for a local North Carolina study area,
§ Internal-internal and external-external travel forecasting for the state of North Carolina,
§ Intercity corridor studies,
§ Through traffic forecasting for regional Metropolitan Planning Organization (MPO) models, and

§ Specialized projects like commercial vehicle monitoring and truck traffic loading profiles on pavement and bridges.

The development of the NC truck network model relied on no-cost FHWA FAF2 trip matrix data representing long haul truck traffic between US and NC counties. The research demonstrated the feasibility of this approach when combined with NC truck traffic count data, VIUS data, NC employment data, national truck trip data, the National Highway Planning Network and the NCDOT Universe File for highway characteristics. The approach did not use or have available the usual travel modeling survey data: NC truck trip rates by employment type, trip length distributions, time-of-day parameters, truck routing characteristics, etc. Empty trucks and back-haul trips were each assumed to represent 30% of the truck traffic, and local truck trips were based on national truck trip data. This hybrid, synthetic approach (combined with careful modeling skills) yielded a calibrated NC truck trip model that match about 460 ground counts at an R2 of 0.93. Compared to VIUS truck travel estimates, coastal, central and mountain region vehicle miles traveled were +11.5%, +0.7%, and -5.7%, respectively, for an overall total of +1.9%.

Recommendations

Model Applications

The NC truck network model represents a foundation for a statewide highway model. Future refinements to the TAZs in metro areas may include linkage to Piedmont Crescent MPO models which are based on census tracts. The Wilmington metro TAZs could be improved by incorporating the proposed port in South Port. Beyond North Carolina the model refinements should include smaller external TAZs and a focus on border crossings to Canada and Mexico, inland destinations, and port destinations for NC truck traffic.

The NC Truck network model also represents a foundation for a statewide multimodal network model including passenger vehicles, trucks, rail, air, inland water way, and marine port operations. Estimating freight transportation flows and transfers between modes is a particularly important multimodal issue because of the connection to NC commerce and economic development. Future versions of the model should start with rail connections at inland and marine ports.

Network Improvements

There are several truck network model issues that should be addressed in the future.

- The NC truck network prototype uses the National Highway Planning Network to be consistent with the FHWA FAF2 data adapted for the research. The NHPN is relatively coarse, and the resulting NC truck network model lacks local roads and streets which are important links for local truck dispatch and deliveries.
- The NCDOT uses the National Highway System (NHS) network.
- The NC truck network model is consistent with the network of highways in 2005.
- During network model development within North Carolina the automatic centroid connector function was used to generate centroid connector links. Future model improvements should more carefully examine centroid connectors and include known truck routes, links to large truck generators, and additional centroid connectors within highly active metro TAZs.

These issues can be resolved in future North Carolina truck network models as more network links are added, perhaps by using the NCDOT Universe File and line work, to include up-to-date highway improvement projects like bypasses and highway widenings (lane additions).

As NCDOT and the State of North Carolina focus more on statewide logistics, future model improvements should also go beyond a strictly truck model and include rail links and intermodal truck, rail and seaport connections. Of particular rail interest are interstate rail systems (CSX and Norfolk Southern) and the North Carolina Railroad corridor. The State ports near Sunny Point, Wilmington and Morehead City should be included. Extending the prototype truck model to a multimodal logistics model will require significant resources and time. Besides the current truck network model, the TransSearch database and the latest version of the FHWA Freight Analysis Framework will provide important model elements, especially networks and commodity flows.

Network Link Speeds

Speed limit data for Interstate and US routes outside North Carolina were not available, so an assumption of a 55 mi/hr speed limit for trucks on US routes and a 70 mi/hr speed limit for Interstate routes was made for all the non-North Carolina routes. For all the North Carolina metro TAZs, a speed limit of 35 mi/hr is assumed. For all the centroid connectors in the buffer and North Carolina rural TAZs, a speed limit of 45 mi/hr is assumed. For all the centroid connectors in the US Bureau of Economic Analysis (BEA) zones, a speed limit of 55 mi/hr is assumed. This approach for setting link speeds is efficient and common practice in national networks that focus on a particular state. However, refinements and other approaches to setting link speed are of interest in future versions of the NC truck network model.

Truck Origin-Destination Data

For the NC truck model the following adjustments were made based on employment: (1) aggregation of trip interchanges for TAZs in the BEA zones, and (2) disaggregation of trip interchanges for TAZs in North Carolina metro areas. The result including BEA zones, buffer counties beyond the NC state line, and NC rural and metro counties was a 357x357 origin-destination (OD) matrix for the NC truck network. The advantage of making adjustments to the FHWA FAF2 synthetic OD county data is that it was available at no cost. However adjusting synthetic OD data involves some level of uncertainty. In addition, the synthetic OD data itself represents a disaggregation of national data to county level OD data. Thus, for future projects it is recommended that NC specific Global Insight Transearch data be purchased. Since the cost of the data is expensive, arrangements should be made to share it with other NC state agencies like the NC Department of Commerce, which may already have access to such data.

The current network model and OD flows only estimate truck traffic, yet intermodal connections and flows are vitally important to North Carolina commerce and resulting economic development. Thus, any purchased data should include intermodal flows.

The FHWA FAF multimodal freight methodology continues to be improved every year, and it can be used as a comparative benchmark for any purchased data. If the comparisons are good, future multimodal network models could revert to the no-cost federal database, perhaps refined by operations research tools available at NCSU.

In the event that public domain FAF2 data must be used instead of purchased data, it is recommended that trip generation rates specific to North Carolina be developed by conducting a trip generation study in the state or by borrowing trip generation rates from other states similar to North Carolina.

NC Truck Trip Assignment

The North Carolina truck network model does not include the passenger vehicle component in the total truck assignment (the sum of the FAF2 long haul trucks and the short haul truck trips). Hence, the multi-path stochastic assignment technique is chosen for assigning the truck trips where all truck trips between an OD pair get assigned to the few shortest paths. The shortest paths are determined by knowing the length of each link and assumed link speeds. Future models should include the passenger car component. Then as most states do for statewide models use the all-or-nothing assignment technique to preload trucks and a static equilibrium technique to assign trucks and passenger vehicles together under capacity constraint. This implies including capacity characteristics to the network in addition to, or in place of, the link speed information currently used.

NC Truck Trip Generation Rates

Short haul truck traffic in North Carolina is estimated based on employment (0.1 truck trips/employee/day). This total average rate does not recognize individual employment categories defined by the North American Industry Classification System (NAICS). The rate is close to the lower end of the rates reported for some U.S. cities. Because the rate is a state average, it does not explicitly reflect intense truck activity such as that experienced at trucking hubs. This limitation is due to the aggregation of truck activity locations into counties and metropolitan areas, as they serve as traffic analysis zones (TAZs) in this model. Future versions of the model should carefully develop truck trip rates that reflect NAICS employment categories within TAZs.

Future Year Forecasts

The base year for the North Carolina truck network model is 2006. Follow-on efforts must determine extrapolations of the base year model to future year traffic in order to examine future highway deficiencies and test alternative highway improvements. A statewide network model with truck and passenger vehicles will permit such traditional evaluations of:

- traffic flow and safety resulting from bridge and highway improvements,
- traffic diversions and detours,
- freight movements to and from special generators like ports and industry,
- economic impacts on cities and towns,
- air quality impacts, especially where the statewide model merges with regional models, and
- future freight logistics if the model is expanded to include rail and port links as discussed above.

Regional and Statewide Model Integration

The NC statewide truck network model can serve as the foundation for integrated, consistent intercity and inter-regional travel demand modeling and forecasting in several ways. Currently each regional model has its own independent external-external and external-internal travel demand estimates for commercial and total vehicles. A statewide network model promises the opportunity to estimate such travel at the boundaries of the regional models and to consistently transfer those estimates between regional model boundaries. Furthermore, a statewide model offers the foundation for forecasts for air quality conformity at regional model boundaries based on consistent travel demand estimates between regions. Also, a statewide truck travel demand model can provide vehicle estimates and forecasts at the project level for roads throughout the state instead of relying on simplistic extrapolations of historic vehicle class counts. It is important to note, however, that the current prototype truck network model is calibrated for the 2006 base year. New and additional data and methods will be necessary to develop future year models for a 2035 design year horizon with 10-year periods for 2015 and 2025 to carry out the model integration discussed above.

Contemporary Issues

A statewide model will also help address contemporary issues such as those posed by the Transportation Research Board in its Fall 2008 solicitation (NCHRP 08-74 [RFP]) for research on DOT performance measures for sustainability. Such measures may be applied ”…at different scales and at different points in system planning and programming; project development, design, construction, and maintenance; and operations”. Such measures may include “…wetland conservation, enhanced economic opportunity, improved air quality, reliable mobility, system preservation, accelerated project delivery, economic vitality, ecosystem services, neighborhood preservation, and increased value of transportation assets. Climate change constitutes an emergent and critical area where agencies need immediate assistance.”

TRB calls for "… achieving the goals of sustainable transportation by developing practical and easy-to-use tools or methods to continuously integrate sustainability into current agency performance measurement programs".

Having a statewide model is another step toward analyzing and achieving a sustainable transportation system.

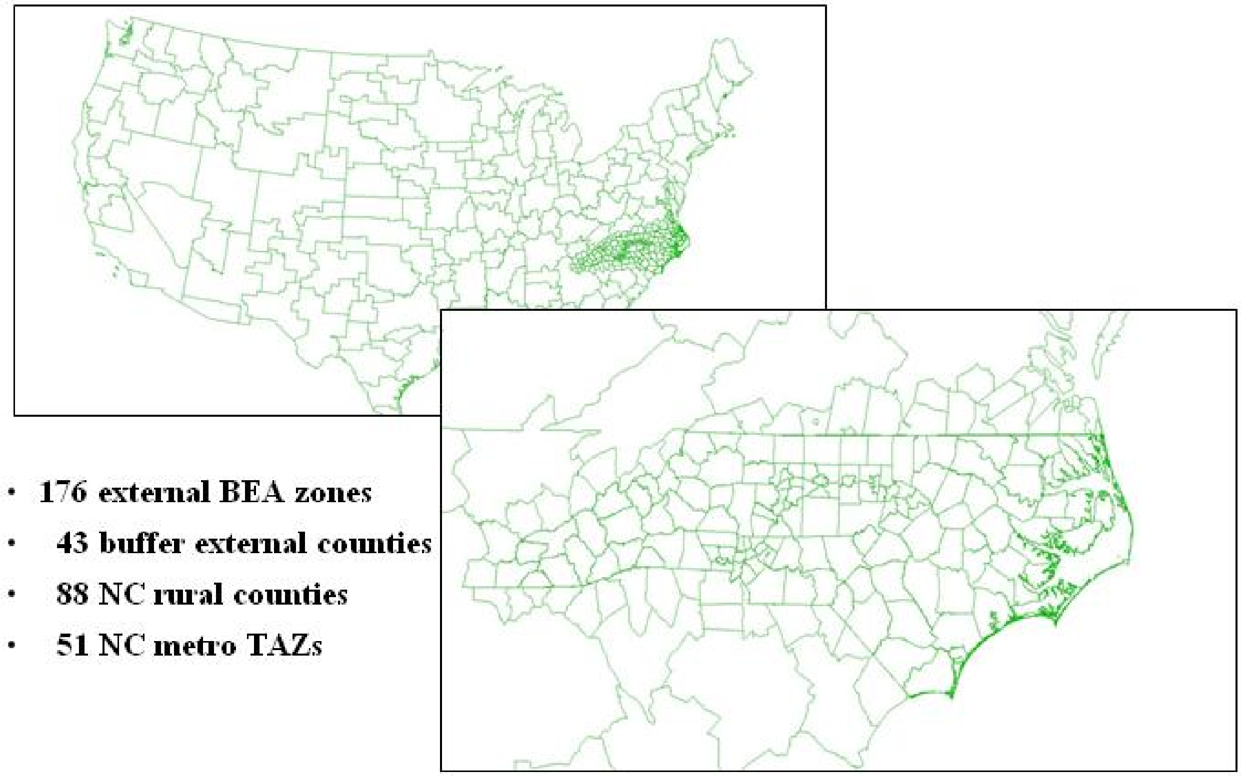

Figure ES - 1 Model Study Areas

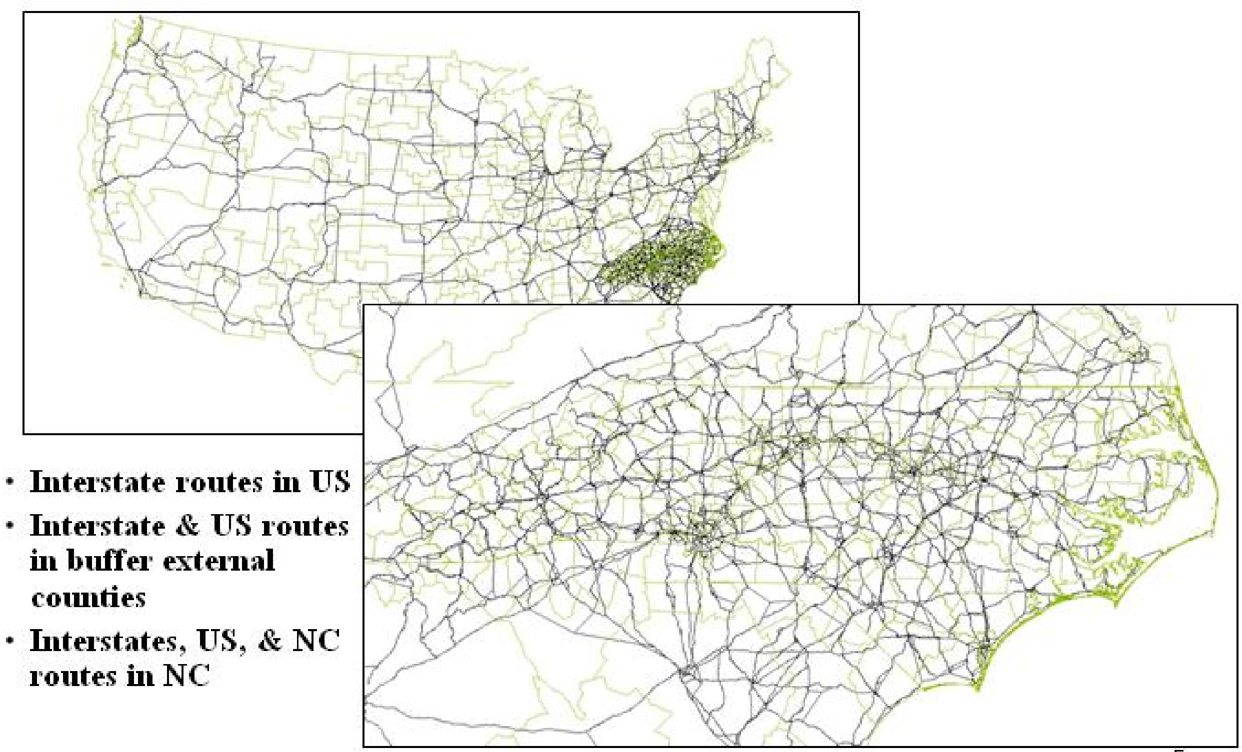

Figure ES - 2 Model Network

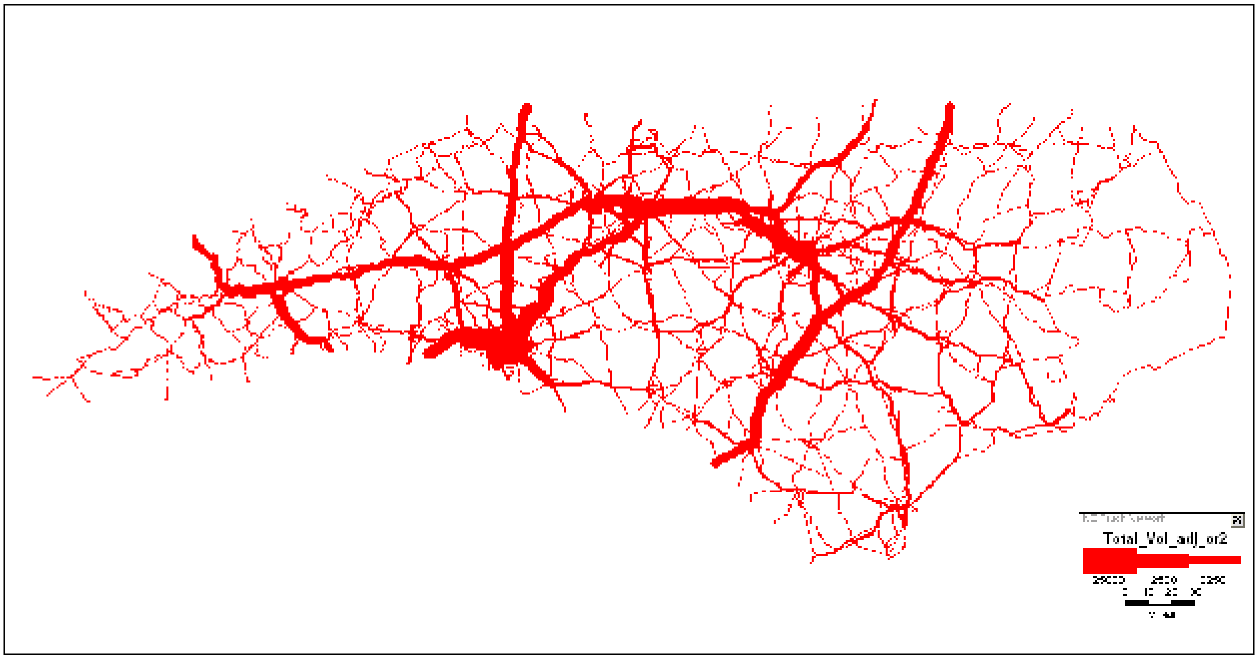

Figure ES - 3 Base Year 2006 Truck Traffic Estimates on NC Network

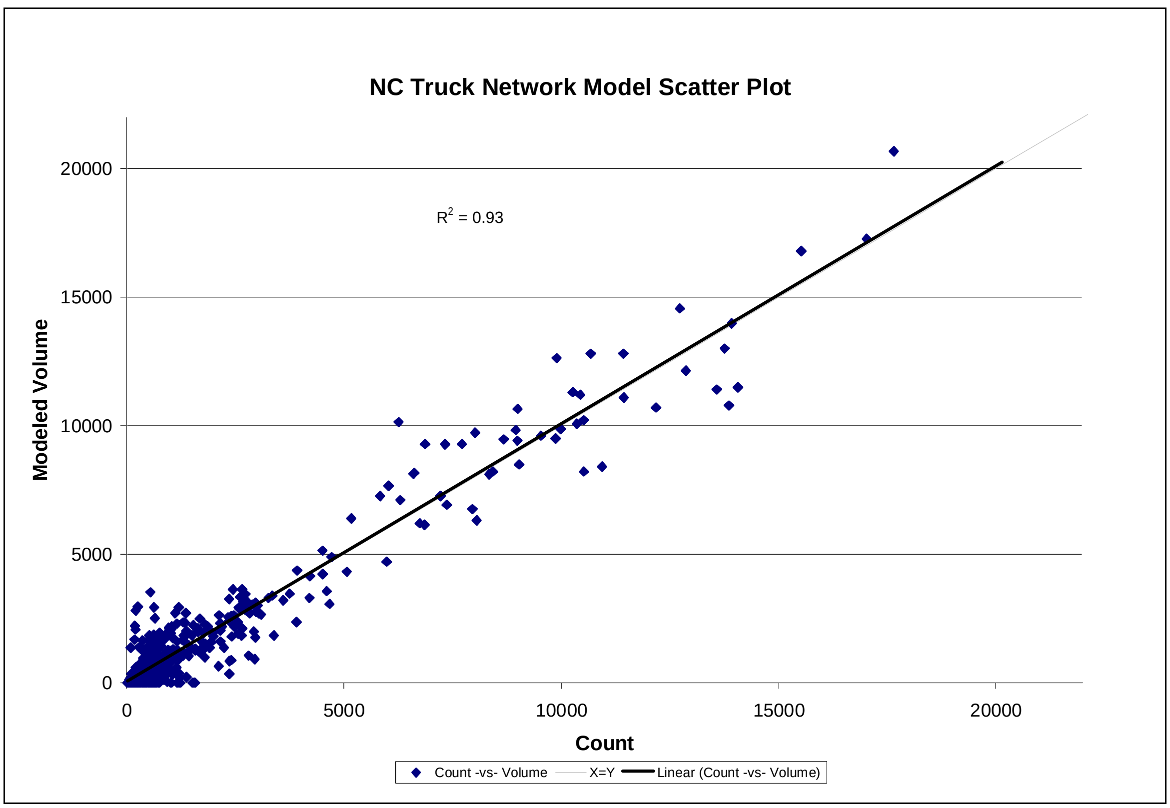

Figure ES - 4 Base Year 2006 Validation – Traffic Scatter Plot

CHAPTER 1 INTRODUCTION

Background

Commodity movement in North Carolina depends on several modes - highways, rail, water and aviation. Of the various modes available, truck transportation is the most vital to industry as it delivers about ninety percent of all manufactured freight transported in North Carolina (FHWA 2006). North Carolina relies heavily on trucks to deliver the products of its diverse economy. The interstate highways of North Carolina carry about 13% of the total U.S. truck traffic (FHWA 2006). Anticipated truck traffic will increase due to economic trends related to rising imports and freight logistics that use just-in-time delivery strategies (EDS 2005). The increased truck traffic will lead to other impacts such as damage to highway pavement, increased congestion and Figure 1 illustrates the importance of trucking to North Carolina and the relative amount of North Carolina truck traffic compared to that in other states. Figure 2 illustrates known freight truck bottlenecks in 2004, especially the one in the Charlotte area. With the expected growth in U.S. and North Carolina truck traffic by the year 2035 as shown in Figure 3, bottlenecks will increase without highway improvements. Indeed FHWA estimates indicate that virtually all current NC Interstate routes will be over capacity by 2020 as a result of truck traffic unless there are highway improvements. Truck effects on US routes are not as dramatic. However, trucks will use more US routes as the Interstate routes become heavily congested. Identifying which US routes will be used by trucks will be important for planning access control and land use, as well as highway design and pavement maintenance.

Thus, the primary objective of this research effort is to develop a base year truck network model for North Carolina that can be used to assess the current truck flows in and across the state. The validated base year model will be the foundation for additional research in a related effort to forecast future year truck traffic and test highway alternatives.

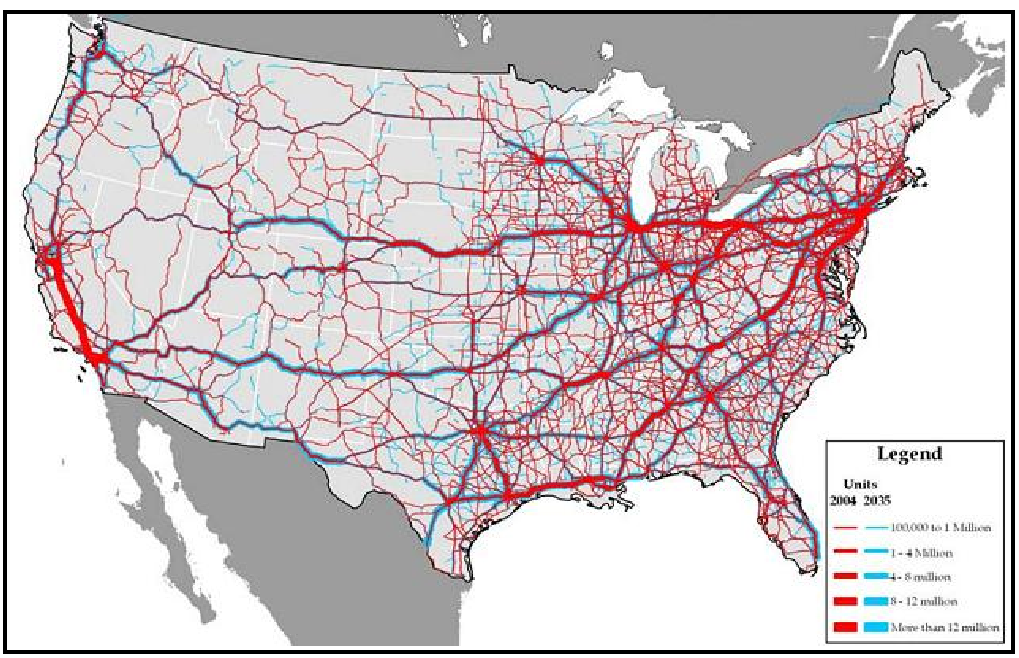

Figure 1 Freight Truck Highway Flows in 2004 and 2035
Source: Cambridge Systematics based on Global Insight, Inc TRANSEARCH 2004 data.

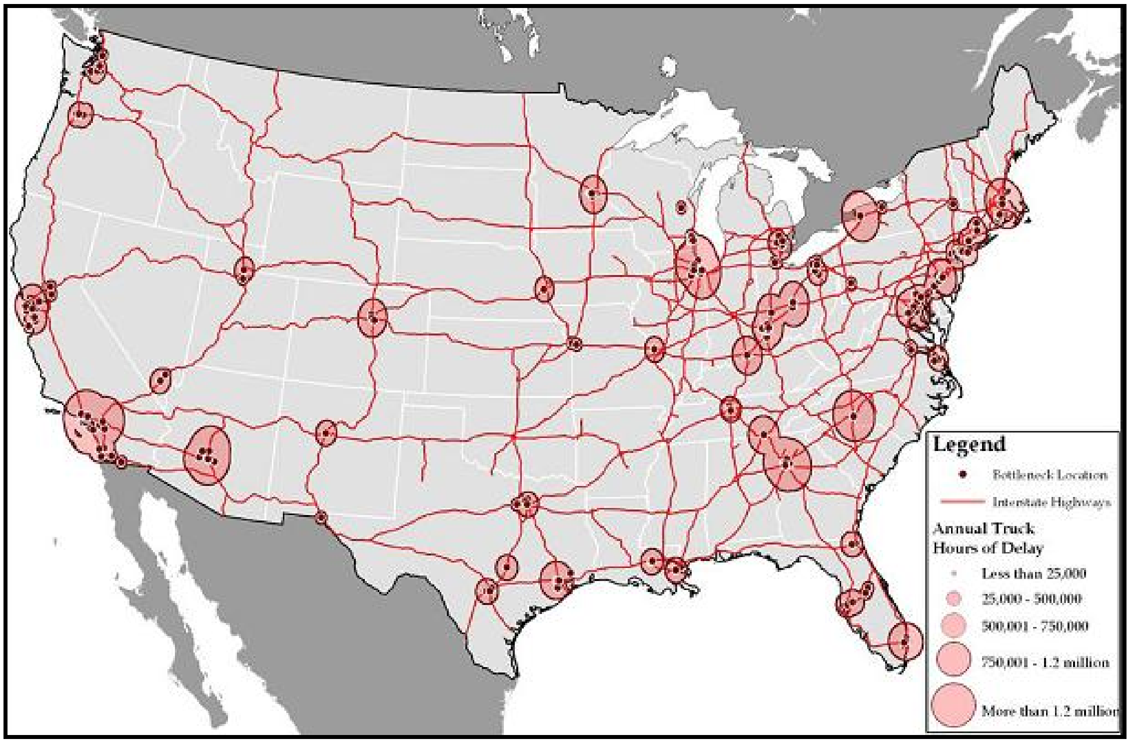

Figure 2 Major Freight Truck Bottle Necks in 2004

Source: Cambridge Systematics, Inc, "An Initial Assessment of Freight Bottlenecks on Highways," prepared for Federal Highway Administration, October 2005

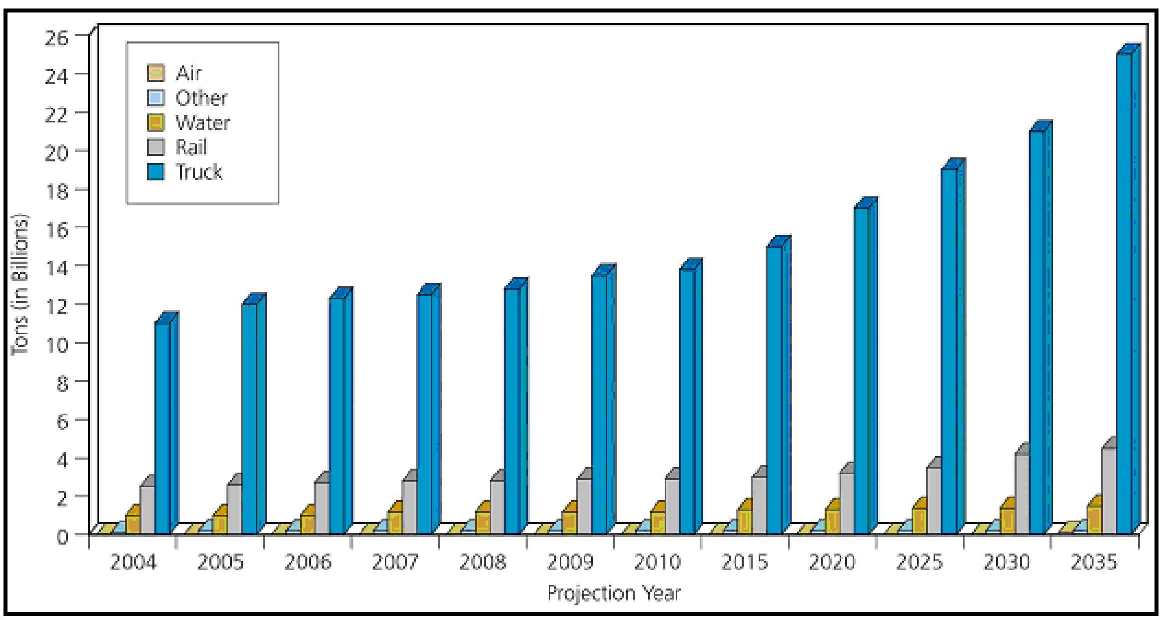

Figure 3 Projected Freight Tonnage Growth by Mode
Source: AASHTO Freight Transportation Bottom Line, John Horsley, Feb 13, 2007
www.ftc.state.fl.us/PDF/Presentations/AASHTO-Freight_Transportation_Bottom_Line_(2-13-07).pdf

Problem Statement

Existing NCDOT regional travel demand models such as the Metrolina model (NCDOT 2004) and the *US 64 Corridor Study (NCDOT 2005)* are either urban or corridor models and they cannot simulate the effects of increasing truck traffic in and across North Carolina. The *North Carolina Statewide Transportation Plan* (NCDOT 2004) states that the traditional long-range transportation planning process focuses on individual communities and regions. The result is gaps in the planning process for highway facilities that support travel between communities and that serve longer regional or intrastate distances. The *Plan* also states that the traditional long-range and project development processes have resulted in isolated, segment-by-segment decision-making based on individual projects rather than overall state highway network needs. Corridor and urban models do not have interconnected links across the state and thus cannot forecast “macro” traffic shifts from one statewide corridor to another. The effects of such statewide traffic divergence are needed to make statewide highway policy assessments.

The foundation for improved truck estimation tools is thus a truck network model which has statewide and nationwide geography. The more focused challenge for this research is to estimate and replicate the current 2006 truck traffic along various highways in North Carolina. This requires development of a base year statewide truck network model using a variety of data sources. It is critical that good truck traffic estimates be prepared so NCDOT roadway and pavement designs and highway improvements can be planned accordingly. The North Carolina truck network model can play an important role in high level public policy decisions, transportation planning and decision making when integrated with a passenger vehicle model. It can address freight transportation planning issues like analyzing the truck traffic growth in the state to assess infrastructure investment options including manufacturing and multi-modal distribution centers, as well as highway improvements. Future, more complex freight models may be able to address trade analysis, economic trends and freight needs, industry trade and transportation needs, modal diversion, and hazardous materials analysis.

Scope

The product of this project is a prototype statewide network model for truck traffic in NC. The base year for the North Carolina truck network model is 2006. Extrapolations of the base year model to a future year in order to forecast future year truck traffic, to examine highway deficiencies, and to test alternative highway improvements will occur in follow-on efforts. TransCAD and ArcGIS software are used for developing the model so that results will be compatible with current NCDOT procedures. The study area for the model is the state of North Carolina. The model thus has a detailed geography inside the state. Traffic Analysis Zones (TAZs) are at county and sub-county levels inside North Carolina. Outside North Carolina the TAZs are at county level geography inside a buffer area that extends part way into neighboring states. The buffer area provides flexibility in the model for traffic diversion on major routes that approach North Carolina. Beyond the buffer across the US interstate network, Bureau of Economic Analysis (BEA) zones are used as TAZs for external zones. The National Highway Planning Network (NHPN) is used as the model network because the network density is consistent with the level of geography selected for modeling. Inside North Carolina the model network includes all Interstate, U.S., and NC routes. It also has other important secondary SR routes that are part of the NHPN. In the buffer area, the model network includes only Interstate and U.S. routes. Beyond the buffer area, the model network consists only of important Interstate routes.

The model uses the U.S. nationwide county-to-county truck flow database called the Freight Analysis Framework 2 (FAF2) that was synthesized by the Federal Highway Administration (FHWA 2006). FAF2 provides annual average daily truck traffic (AADTT) flows between each county in the U.S. However, the FAF2 truck trip matrix provided for NCDOT by FHWA is not categorized by commodity type or vehicle type. The resulting North Carolina model thus uses existing and freely available synthesized data (FAF2, FHWA 2006) rather than purchased proprietary truck origin-destination surveys. It is important to note that since FAF2 is a synthesized commodity-based nationwide database, it ignores service-based truck trips, which are mostly short haul trips and account for a big portion of total truck trips. To address this deficiency North Carolina Employment and Security Commission (NCESC) employment data are used to estimate missing short haul trips. About 460 48-hour NC truck traffic counts collected by the NCDOT Traffic Surveys Unit are used for model validation. Growth factors are applied to develop consistent year data to compare the base year model flows with truck counts.

Research Objectives

The goal of this research is to develop a statewide network model for estimating base year truck traffic in and across North Carolina. The specific objectives of the project are as follows:

- To review and evaluate the statewide and sub-state network models currently being used by other state DOTs and the USDOT.
- To select a model framework that can be used in North Carolina to conduct highway project assessments, especially regarding truck traffic.
- To develop a prototype truck network model.
- To validate base year truck network model using truck traffic counts as well as other available observed data.
- To identify lessons learned regarding the use of national truck data, in particular the FAF2 database, and to outline steps for future research.

Overview of the Research

This chapter introduced the need and importance for developing a statewide truck network model for North Carolina. As a result of economic conditions, import trade, and new logistics strategies, freight delivery by long haul trucks has increased significantly in recent years and will likely continue to do increase in the future. Thus, North Carolina highways which serve as vital interregional and national links will carry more truck traffic in the future. The network model coming from this research can serve as a new tool to identify future highway deficiencies and test new highway improvements.

The research specifically develops a calibrated and validated base year 2006 truck network model for North Carolina. It uses the 2005 National Highway Planning Network including Interstate, US, NC and some SR routes in North Carolina. The network extends beyond North Carolina with US and Interstate routes in order to capture external traffic effects as far away as the West Coast, as well as surrounding neighboring states. Traffic analysis zones include metro, county and Bureau of Economic Analysis areas. Besides long haul data based on synthetic FAF2 truck origin-destination data, short haul traffic model is also developed. The base year model is validated against about 460 traffic counts throughout North Carolina in order to meet FHWA validation guidelines.

Organization of the Report

The second chapter of this report provides a summary of literature regarding various urban, statewide and national truck models. The second chapter also summarizes various data sources that can be used for developing a statewide model. The third chapter describes the methodology involved in developing the North Carolina truck network model. The fourth chapter describes the procedure to calibrate and validate the based year model and presents the validation results. The fifth chapter demonstrates the application of the model for analyzing the traffic impacted by a bridge work zone on I-40 and the use of the model for statewide and regional VMT derivation. Finally, the sixth chapter summarizes findings, conclusions and recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

Literature Review

This chapter highlights forecasting procedures, data and software applications used in truck traffic forecasts and truck network models.

Over the past few decades, various methodologies have been developed and applied for predicting freight movements. Statewide truck traffic models are utilized in some states such as Iowa, Florida, Virginia, Kentucky, Wisconsin, Indiana, California and Louisiana. Other states use highway segment by segment forecasting procedures based on time series analysis, statistical projections, and qualitative methods. The following literature review addresses the advantages and disadvantages of candidate truck traffic estimation procedures for North Carolina and their data requirements. This literature review lays the foundation for developing a prototype truck traffic network model for North Carolina that will be useful for policy analysis and that will be a precursor to detailed network models appropriate for planning studies.

Ideally a truck network model should be able to:

- replicate base year truck traffic on the North Carolina truck network,
- forecast future truck traffic on the network,
- forecast future truck traffic as the state and national economies change, and
- demonstrate alternate truck traffic flows for alternative highway network improvements and for alternative economic development strategies.

This literature review builds on the report *NC Truck Traffic Forecasting* (NCDOT, 2006). It evaluates the network model options for NCDOT, and it discusses possible data sources. The first section provides a summary of methods for truck forecasts on highway segments. The subsequent sections provide a review of four-step network models, commodity flow models, and synthetic OD models. The review discusses network models developed by other states, and it describes U.S. and regional implementations for FAF, GEOFREIGHT and LATTS. Model data needs and sources including Transearch, VTRIS, and NCDOT are discussed. The review concludes by reviewing recently released literature on truck network models and proposing a candidate model and data sources suitable for North Carolina.

Factors Affecting Truck Traffic Demand

Besides highway infrastructure planning and design, forecasting truck traffic is an element of the overall multi-modal freight transportation planning process. It is a critical component that drives many of the decision-making processes that determine freight transportation system improvements, support infrastructure investment, and guide policies and regulations affecting air, rail and water modes. Truck traffic forecasts are important because trucks and rail together carry about 70 percent of the U.S freight tonnage and 80 percent of the total value of U.S. shipments (FHWA, 1998).

In order to ensure that a proposed truck traffic estimation tool is responsive to planning and policy processes, causal factors that affect truck traffic should be identified and verified in the tool. However, due to a lack of good data on these factors such as uncertain political, technological, economic, and societal events, relatively simple statistical models that extrapolate past trends are frequently used.

Causal factors may directly or indirectly affect truck traffic demand. Direct factors are those that contribute to the demand for goods and services and therefore directly lead to the demand for trucks as a mode of freight transportation. These factors are broadly identified in the Quick Response Freight Manual (Cambridge Systematics, 1996) as follows:

- Macroeconomic factors: the level of economic activity, international trade, and other economic phenomena.
- Demographic factors: changes in overall population, age distribution, employment distribution, and spatial location.
- Socio-economic dynamic factors: changes in the habits, values, perceptions, and lifestyles of people over time.

Data sources for direct factors are relatively easy to find for cities and counties, but these aggregate jurisdictional data are hard to incorporate into typical regression models to forecast truck traffic that may vary on highway segments in the same city or county. The problem is complicated when highway segments cross jurisdictional boundaries and direct factors change abruptly.

Unlike direct factors, indirect factors are those that influence truck demand by affecting the cost and level-of-service of truck transportation services. These factors may be generally classified as:

- Government policy: user charges and taxes, environmental and safety regulations, subsidies, and other public sector institutional issues.
- Freight logistics: just-in-time delivery, centralized warehousing facilities, industry alliances, and demand-responsive scheduling.
- Transportation infrastructure: the design, operation, and level-of-service of multimodal and inter-modal facilities.
- Technological advances: intelligent transportation systems technologies that greatly aid in the efficient operation of freight transportation systems and logistics communications.

Indirect factors might also include unexpected events – war, natural or man-made disasters, economic upheaval, etc. Information on indirect factors is hard to find and incorporate into simple truck forecasting methods. Such information is usually applied in complex simulation models and probabilistic models. Figure 4 constitutes a simplified representation of the direct and indirect factors that affect truck volumes.

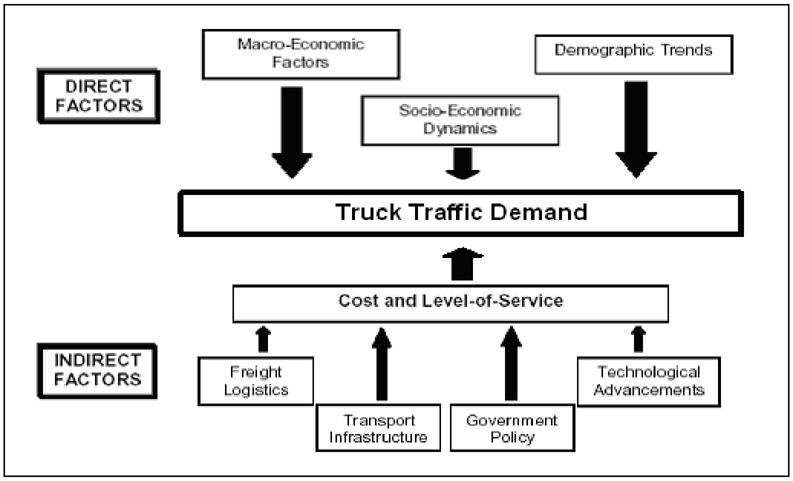

Figure 4 Factors Affecting Freight Transportation Demand (Source: NCDOT 2006)

Truck Traffic Modeling Methods

Various truck traffic modeling methodologies have been developed and applied. The simplest and least data intensive methods are statistical models based on past historical counts of truck traffic, and sometimes direct and indirect causal variables like indicators for business activity. Such trend models focus on highway segments that are candidates for near-term construction and repair. But statistical models for estimating truck traffic on individual highway segments do not permit evaluation of network effects like congestion, alternative network improvements, and changing land use and economy. For more information on statistical models, see NC Truck Traffic Forecasting (Stone, 2006).

More complicated and geographically broad truck network models share planning procedures – trip generation, distribution, mode choice and assignment – that are characteristic of traditional urban and regional traffic models. Freight network models have three categories: 1) urban truck network models, 2) statewide or regional commodity flow models, and 3) statewide truck network models. The different approaches are the result of differing priorities at each level. Planners in metropolitan areas are typically concerned with alleviating roadway congestion, while regional planners tend to focus on issues of economic competitiveness and efficiencies. The planners focus upon how they view freight movements. Urban planners tend to deal with the externalities associated with trucks such as urban traffic congestion, while regional planners tend to focus on the economic interchanges between various zones within the region that accompany freight movements. In general, network models assume that shippers and carriers use minimum cost paths on a network where the cost is a combination of price and time. The networks are modeled with an array of traffic analysis zones and origins and destinations that produce and attract vehicle trips and freight in response to system demand. Network models for freight logistics hold promise for modeling urban and intercity truck flows. They are more complex to implement than other methods and have more intensive data requirements. Yet, a number of cities and states have truck and freight network models. Thus, the implementation of network models for truck traffic is a viable strategy for statewide truck traffic demand forecasting. At the interregional and national levels the FAF, GeoFreight, and LATTS models have been used by federal and state agencies. They are discussed subsequently.

There are two modeling techniques employed in forecasting truck network flows – commodity flow models and trip based models (Raothanachonkun, 2007). Both approaches are typically employed in a “four-step” sequential process that uses a gravity-model distribution, a mode-split step and trip assignment. The only significant difference is that the trip generation step is based on freight flow data (usually classified by industry groups) in commodity flow models, instead of regression equations for employment and population, as with trip based models.

A good example of the commodity approach is the Indiana Freight Model (Bernardin, Lochmueller & Associates, 2004). The Indiana model predicts both truck and rail traffic volumes. For each of 21 commodity groups, trip generation equations are developed based on a regression of data available from 1993 Commodity Flow Survey (CFS). Following trip generation, freight shipments are distributed by a gravity model, which is also calibrated using the CFS data. The mode split step also utilizes the 1993 CFS, projecting the 1993 national shares into the future. Next, the model divides the freight tonnages into an equivalent number of vehicles, with tons-per-vehicle payload factors determined separately for each commodity group. Finally, the traffic is assigned to the network. This approach builds the relationship between commodity flow and truck traffic. It takes economic activities into account using the familiar four-step travel demand methodology to forecast future truck volumes. However, such a model is complicated and requires much survey and quantitative data.

The commodity flow-based technique is also used in the Wisconsin Intermodal Freight Model (Wilbur Smith Associates, 2004), Kentucky Freight Model (Wilbur Smith Associates, 2005), and the Southern California Freight Planning Model (Fischer, 2003). Based on commodity flow forecasts and economic input-output modeling techniques, the procedure for Southern California Freight Planning is notable. It classifies heavy-duty trucks by three gross vehicle weight rating classes: light-heavy, medium-heavy, and heavy-heavy. Commodity flows are then converted to truck trips using the commodity-specific estimates of the portion of tonnage carried in each truck weight class and the average truck payload for each weight class.

The following sections describe examples of urban, state and national truck trip and commodity-based models.

Urban Truck Trip and Commodity-Based Models

The FASTrucks model (Cambridge Systematics, 2000) is a regional truck trip forecasting model used in the Seattle, Washington region. It operates in tandem with the region's person travel model, sharing data where appropriate. It is an adaptation of the three-step travel forecasting process: trip generation, trip distribution, and traffic assignment. The FASTrucks model is based primarily upon average national truck data or information imported from elsewhere. No Seattle truck travel behavior data were available to the modelers, and only limited truck count data were supplied. The authors acknowledge the overlap between such trips in the truck and person travel models, as well as the inability to separate commercial trips and personal trips. Trip generation rates for each category were derived from the Quick Response Freight Manual (Cambridge Systematics, 1996). The relative attractiveness of each industry determined its share of the total trips attracted. The input-output data, expressed in dollar terms, were scaled to the total trip generation. A simple gravity model matched trips from the generators and attractors.

The Cincinnati-Dayton freight model (Gliebe, 2002) consisted of roughly 3,000 traffic analysis zones which were condensed into 150 freight analysis zones with increased detail along I-75, the major north-south highway in the region. A seed matrix was developed using average values and parameters from the Quick Response Freight Manual (QRFM). The model was designed primarily to evaluate short-term scenarios, although the capability to complete long-range forecasts was required as well. A Delphi process was originally proposed to develop long-range forecasts of major activity locations and trends in economic markets and trucking. This model has the critical attributes of a truck network model that could be extended into a statewide implementation such as replicating base year truck traffic, generating long term future truck traffic, forecasting future truck traffic for different policies, and demonstrating alternate truck traffic flows for future development scenarios.

TransCAD was used for implementing the matrix estimation process. In general, larger scale projects in urban areas used regional transportation software packages like TransCAD. It is an integrated transportation software package that can be used as a tool to help estimate link volumes and turning movements for base year networks, and it also estimates future year traffic based on changes in causal variables such as land use or employment. TransCAD offers a set of tools for modeling commodity flows and truck movements in which truck traffic can be easily assigned to the transportation network.

The New York City Best Practice Model (List, 2002) developed for New York City couples an extension of traditional matrix estimation techniques with estimates of zonal trip generation and attraction to derive the truck flows. The matrix estimation model is a linear programming solution that minimizes the deviations from the observed values while conserving the flows in the seed matrix. A multi-objective math programming is used to estimate the OD matrix that is best compatible with set of ground counts available. This novel method of matrix estimation is different from the existing techniques in that it has high tolerance for inconsistent observations. The model is highly under constrained with many variables and relatively few constraints and hence has high flexibility in setting the importance of various input datasets and observations. Some of the datasets used in the model include directional link volumes, partial OD matrix values, total trip ends for each zone and screen line counts. The model has recently been applied to the New York City region, on a 405 zone network containing about 76,000 one-way arcs. The model uses a linear programming method to minimize errors in suspicious data. Suspect counts were subsequently reviewed or corrected, as well as network coding errors. The model demonstrates matrix methods that are fundamental to a statewide network model. However, a major limitation of the model is that it cannot forecast future year flows.

The Highway Economic Requirements System (HERS) estimates the future investment requirements of the nation's highways system for the U.S Congress (FHWA, 2002). The relative costs and benefits of various alternatives can be simulated using HERS, and, hence, it assists planners in appropriate decision making. The HERS models include simulation of maintenance, traffic congestion, safety, operating speeds, and air pollution. It also simulates the performance of the highway system over a series of time periods. The Ohio DOT applied HERS in evaluating macro-corridors of Ohio using Highway Performance Monitoring System (HPMS) data prepared by the Ohio DOT. Hence, HERS also finds application in urban area projects/corridor studies for analyzing situations with base truck traffic and with forecast future truck traffic.

Statewide Truck Trip and Commodity-Based Models

For statewide network models, planners usually use the four-step approach, which includes freight generation, distribution, modal split and route assignment. Both commodity-based and vehicle-based models have been used.

The vehicle-based or trip-based approach typically estimates the number of trips according to socio-economic data, (particularly industry type and employment) and land use characteristics, as well as trip survey data. The trip-based approach can be fully integrated into the traditional four-step traffic demand analysis framework, which includes trip generation, trip distribution and trip assignment. The *Quick Response Freight Forecasting Method* developed by Horowitz (1996) is an example vehicle-based method that applies short cut methods and parameters to avoid costly surveys and data gathering.
Commodity-based models focus on commodity generation, commodity distribution, mode split and trip assignment. The commodity-based approach first analytically generates and distributes or acquires sampled region-to-region, state-to-state, or county-to-county tonnage flows from a proprietary source like Global Insight Transearch. Second, the commodity-based approach allocates the commodities to the different transportation modes (e.g. truck, rail, water). Third, the commodity approach converts tonnage to the number of truck trips based on a payload factor and assigns the truck trips to a state or regional network. The *Freight Analysis Framework* model (Tang, 2006) is a commodity-based model that provides researchers with resulting commodity origin-destination data at the commodity flow survey district level and with synthetic truck trip origin-destination data at the county level.

At least ten states have operational statewide truck models (Indiana, Wisconsin, Texas, Kansas, Michigan, Ohio, Maine, New Mexico, Oregon, Montana, New Jersey, Kentucky, Louisiana, and Virginia). Most statewide models have taken hundreds of thousands of dollars and several years to develop and refine (NCHRP 358, 2006). These states mostly apply commodity flow principles, except New Jersey and Virginia. They apply techniques described in the QRFM (FHWA, 1996) or in the Statewide Freight Forecasting Report (Cambridge Systematics, 1997). Working from employment estimates, these truck models are quite similar to the FASTrucks model, except for the application at a larger geographic scale. None of the statewide models are true commodity flow models; rather they are hybrid formulations that incorporate elements of both flow models and multi-step models. The Michigan and Wisconsin statewide models are such examples (Donnelly and Arens, 1997; Sorratini, 2000). The models often employ linkages with input-output models primarily to match employment with commodities. Some models use gravity distribution models and others use more complex logit-based destination choice models. Only sparsely populated and predominately rural New Mexico uses synthetic matrix estimation techniques on a statewide basis (Oxford Systematics, 2002).

The preferred method of traffic assignment depends on the network detail. Historically, many statewide models (Maine, Michigan and Montana) have used the all-or-nothing assignment technique where all the trips between an origin and destination are assigned to the shortest path between them (NCHRP 358, 2006). Many freight components still use all-or-nothing with to preload trucks to a network as it is commonly believed that long distance truck drivers do not or cannot easily change their paths due to congestion. Preloading is often done with an all-or-nothing assignment. Dynamic all-or-nothing technique is a variant of all-or-nothing method where trips are assigned in small intervals. Dynamic all-or-nothing technique has an advantage in statewide modeling as it can estimate peak hour traffic in urban areas. None of the states used dynamic all-or-nothing assignment (NCHRP 358, 2006). Static equilibrium traffic assignment is a method by which traffic is assigned such that the link travel times are consistent with the volumes. The static equilibrium assignment method is selected by most states for assigning trucks and passenger vehicles together (NCHRP 358, 2006). Stochastic multi path assignment is a technique in which trips between an origin and destination are assigned to multiple paths, with the shortest path getting the largest share. Virginia statewide model uses stochastic multi path assignment (NCHRP 358, 2006).

Compared to trip or vehicle-based models, it is commonly believed that commodity-based models better reflect the economic factors affecting freight flows. Model practices in the states of Indiana, Wisconsin, Kansas, Ohio and Texas have been based on such commodity flow data. In the case of Wisconsin (Wilbur Smith Associates, 2004), an input-output (I-O) model was used for planning and the gravity model was applied in the distribution stage with truck trip data that was converted from commodity flow data. A fully constrained gravity model was used in Indiana (Bernardin, Lochmueller & Associates, 2004) to distribute the traffic based on the 1993 Commodity Flow Survey. The Kansas statewide freight model (QRFM, 1996) was based on agricultural commodity flow data. The commodity flow was converted to truck trips and the external-internal and internal-external flows were distributed using the gravity model.
Virginia DOT used the four-step approach and the gravity model for distributing freight flow at the statewide level (Brogan, 2001). Using forecasted socioeconomic factors, the projections of freight production and attraction of each zone were calibrated and calculated. Accordingly, future year freight flows were forecasted. The whole process is based on the commodity flow data, rather than on truck trips. The commodity flow data from Global Insight Transearch was used. The trucks are preloaded using all-or-nothing assignment and then passenger vehicles are loaded with an equilibrium multi-class assignment. Virginia implements sub-zoning for traffic assignment to avoid lumpy traffic assignments.

In New Jersey (Kenneth, 2000), the existing five regional models were combined to arrive at the statewide model using a truck trip four-step framework. The model development was justified by the facts that the five regional models covered the whole state and a new costly four step model development could be avoided. One of the goals of developing the New Jersey statewide model was to estimate the trucks and commodities moving within and through the state. The five networks and the corresponding trip tables were merged. However, the existing models could not estimate base year truck behavior and thus, additional attributes were incorporated while merging the networks. Commodity flows were established on a county to county basis and truck inventory data were used to establish the tonnage to truck conversion factors. A gravity model generated the truck trip tables.

The Oregon DOT conducted a commodity flow study to develop base year 1997 estimates and future year 2030 forecasts (Louch, 2005). Estimates and forecasts were developed for all the six metropolitan areas of Oregon. To develop the statewide estimates, the team modified an earlier study on the Portland area by using additional data sources. Since they are oriented to a particular direction, the flow estimates for larger regions cannot be aggregated from the available data. In general, the commodity groupings were identified for adjustments by comparing the Transearch data with the Commodity Flow Survey data. Estimates were also adjusted by information obtained by contacting freight industry associations and individual firms.

Statewide freight and truck models have been successfully applied. However, there are certain obstacles which the modelers are yet to overcome. Statewide models are not yet fully integrated to the urban models within the state and they invariably yield to urban models, if there is a disagreement (NCHRP 358, 2006). Many statewide models adopted a zone structure that is county level or an aggregate of counties. Due to the coarse zone and networks used in statewide models which lead to lumpy assignments, most states do not expect the models to validate as well as the urban models.

Nationwide Network Models

To understand freight demands, assess implications for the US surface transportation system, and develop policy and program initiatives to improve freight efficiency, The Freight Analysis Framework (FAF) model was developed (FHWA, 2002). It is a policy tool, intended to estimate commodity-based freight flows for several modes and predict future demands. It supports decision makers in finding appropriate methods to improve on freight productivity. The FAF covers the entire United States and contains data on truck, rail, maritime, and air commodity flows down to the county level. Travel impedance was calculated for each link in the network. The Traffic Analysis Zones considered in the analysis are counties. The FAF contains estimates for truck tonnage flows in a county-to-county origin-destination matrix. The conversion of the tonnage flows truck volumes is also presented. The output of the FAF is in the form of an ArcGIS shapefile that allows customized presentation. All output data tables can be linked to the shapefile and data of interest can be extracted and displayed as necessary. The FAF freight flow data are based primarily on the 1998 version Transearch data and HPMS data. To evaluate the effect of anticipated truck volumes upon the network, the FAF uses a base year 1998 network and includes economic forecasts and resulting commodity and freight flows for the years 2010 and 2020.

In 2005 FHWA began to update and modify FAF, now known as FAF2 (FHWA, 2006), which is primarily based on 2002 Commodity Flow Survey data. Features are similar to FAF1 and include downloadable origin-destination (OD) commodity data at state, Commodity Flow Survey district, and county levels. Also being developed are a 2002 base year truck OD matrix, a truck traffic assignment using the National Highway Planning Network, and future year forecasts to 2035.

The GeoFreight Intermodal Freight Display Tool was created in a joint effort between FHWA, BTS and USDOT with the objectives of graphically displaying freight movements and guiding policy makers in identifying bottlenecks on the nation’s highway, railway and water transportation networks (FHWA, 2004). GeoFreight is GIS-based, but can be used independent of a GIS software package. It allows for graphical display of interstate freight flows, and it includes national origin-destination information. The GeoFreight database uses the same freight volumes contained in the 1998 and 2010 FAF datasets. The GeoFreight database further includes information on US transportation infrastructure and calculates a ‘nominal capacity’ for each segment. This ‘nominal capacity’ corresponds to the average traffic flow for a particular facility type and allows estimation of the utilization level of a segment compared to the national average. GeoFreight uses equilibrium assignment technique to assign flows to the network. The three major features of GeoFreight are its ability to create thematic maps, analytical maps, and summary tables for a specific area of interest. The thematic maps allow for graphical display of freight facilities, freight flows and congestion data from the Highway Performance Measurement System (HPMS). With the analytical maps the user can simultaneously display different freight modes and can further display region or link-specific origin-destination information by state. The software therefore allows a basic analysis of specific ports or bottlenecks of interest. For example, GeoFreight can display the origin-destination information by state for all goods moved through a segment of I-95 for the base year 1998 and for the 2010 forecast. However, GeoFreight does not allow the user to access the actual GIS files. While this has the advantage that no additional software is required, it significantly limits the software for custom applications and is not as user-friendly as an actual GIS software program. Finally, the program is capable of providing summary tables of the analysis that can then be used for presentation purposes.

Several southeastern U.S. states and several countries in Latin and South America joined together to develop the Latin American Trade and Transportation Study (LATTS). The objective was to assess freight movements and border crossings between participating entities. The completed LATTS study and its findings are published and all documentation is available (Wilbur Smith Associates, 2002). The actual LATTS database is proprietary. The objective of the project was to aid large scale policy decisions on the regional or national level; LATTS does not attempt to assess freight movements at the local level. Hence, compared to FAF and GeoFreight, the LATTS highway system is rather coarse. It consists only of interstates and a few selected major US routes. In North Carolina, the modeled US routes include most of US74, as well as, parts of US17 and US23. Other important routes, such as US64 are not included in the study scope. To facilitate the analysis, each highway was assigned to one of the 25 LATTS Trade Corridors. The corridors only represent virtual freight movement links derived from the origin-destination database that extends beyond the boundary of the LATTS Alliance and connects to major freight gateways nationwide. The calculated truck flows were assigned using GIS-based shortest path models. The final report also includes a broad discussion of current and future freight logistics and infrastructure needs and points to the importance of Latin America to the US economy.

The TLUMIP Commercial Travel Model (Donnelly, 2002) is a bi-level hybrid simulation, consisting of an upper-level regional commodity flow model and a lower-level microscopic model of truck flows. The flows are represented as annual origin-destination flows between different sectors of the economy, expressed in current dollar terms. The upper level of the model transforms these estimates into tonnage flows by commodity and mode of transport. The lower part of the model is an agent-based micro simulation of goods movement in the region. Monte Carlo simulation is used for generation of discrete shipments, micro simulation of trip ends, trans-shipment allocation, and itinerary generation. A traveling salesman problem solution is used to sort the destinations on each itinerary. The simulation makes extensive use of observed data from a variety of sources, to include nationwide commodity flow and vehicle utilization surveys. Data from truck intercept surveys in Oregon and Canada were also used. The model has been validated in tests in Portland, and further development work is ongoing.

Model Summary

Based on the above review of various urban, statewide and national models, four models stand as candidates for North Carolina: three-step model, four-step model, commodity flow model and synthetic model. The data requirements, benefits and drawbacks of these three models are summarized in the Table 1,Table 2, andTable 3. Picking a model format from Table 1 for this research was determined by the data requirements of the model and the availability and cost of the data. Hence, the next section of this chapter will review model data requirements.

Data Sources

Finding appropriate, accessible, and reliable data is a big challenge for freight flow estimation. Ideally, the analyst would like to have accurate data on commodity flows by industry sector, mode, origin and destination at the TAZ level to identify flows on specific routes or at specific locations. In this section, various data sources that can be used in freight modeling are identified. Table 4 shows a summary list of potential sources of data, the scope, availability and extent of each source, and a list of local and state agencies which have used the data source in developing freight models.

Global Insight Transearch data is the primary commercial source of commodity flow data when developing a commodity flow model (Ahanotu, 2003). Ahanotu described a procedure to create a commodity flow database by critically analyzing Global Insight Transearch data. The study was based on the commodity flow database developed for the Portland metropolitan area. The under-represented data elements in the Transearch database were prioritized to provide transportation planners with a more complete database for analysis. The study identified the potential supplementary databases that could be useful such as the Commodity Flow Survey (CFS 2002), and reports of the Oregon departments of agriculture, geology, energy and environmental protection. The study also established a procedure for routing trucks based on these supplemental sources. Finally, the validation and refining of Transearch database were done by comparing similar data with CFS data.

Table 1 Candidate Models: Summary of Data Requirements

Model	Data Requirements
Three-step Model	Travel survey data, goods movement data, extensive classification count data, employment data by category type, special truck generators, weigh station data, truck inventory, extensive network data, and trip length distribution.
Four-step Model	All of the same data plus additional survey data, railway data, and roadway attribute data.
Commodity Flow Model	Goods movement data, population and employment data, coarse network with basic data, trip length distribution minimal classification count data.
Synthetic Models	Synthetic OD trucks/freight data, employment data, coarse network with basic data, trip length distribution, truck count data.

Table 2 Candidate Models: Summary Advantages

Model	Advantages
Three-step Model	Predictive model. Detailed level analysis. Can model a greater number of commodity flows.
Four-step Model	Same as above. Can model a greater number of mode classes.
Flow Model	Low cost. Sketch level development and implementation. Straight forward application
Synthetic Model	Low cost. Acceptable level of estimates in case no flow data are available

Table 3 Candidate Models: Summary of Disadvantages

Model	Disadvantages
Three-step Model	Data intensive. High data collection cost. Expensive to develop. High development and implement time.
Four-step Model	Same as above. Requires advanced user knowledge.
Flow Model	Static model in current state. Coarse level of geography.
Synthetic Model	Poor synthetic OD estimates lead to poor truck assignments.

Freight Analysis Framework 2 (FAF2) is an alternative data source that can be used at no cost if funds are not available for purchasing Transearch data. FAF2 includes synthetic estimates of county to county truck flows among major metropolitan areas, states, regions, and international gateways. It provides average annual daily truck OD estimates for 2002 (FHWA, 2006). FHWA provides forecasts for 2010 to 2035 in 5 year increments, which can be downloaded from the FAF2 webpage for free.

The Commodity Flow Survey (CFS) can be useful in validating the estimated freight model. The data is available in ASCII data format (FHWA, 2002). The files can be downloaded in a comma delimited format for analysis in spreadsheets. Vehicle Travel Information System (VTRIS) data, state DOT traffic counts, and DOT and MPO corridor surveys and external station traffic counts can also be used for validating the freight flow models. Transborder surface freight data can be used for obtaining the commodity flows across the US border. Employment data is available from the state employment and security commissions and can be used in conjunction with trip generation rates from QRFM manual to generate truck trips by each employer. The Vehicle Inventory Usage Survey (VIUS), conducted by US Bureau of Census every five years, has detailed information on the physical and operational characteristics of the US truck population. It can be used for deriving the truck tonnage to truck trips conversion factors (US Census Bureau, 2004).

The trip generation data can thus be obtained and/or synthesized from the above data sources. If OD data are not available, the growth-factor model or gravity model could be used. The ***growth-factor model*** expands the existing interzonal flows by means of zonal growth factors. If only the trip end data at the origin and destination are available, the growth-factor model can be applied. This model is a simple process that does not consider any trip impedance. In freight planning practice, the Fratar growth-factor model is sometimes used to establish rough estimates of the statewide growth in freight flow. For external-external interstate flow distributions where the socio-economic data are not available, the growth-factor model may be applied. The ***gravity model*** is widely adopted in statewide freight trip distribution, especially for internal truck trip distributions. The gravity model is calibrated by comparing the trip length distribution and average trip length to observed values if available. Otherwise, traffic count data collected can be used to calibrate the gravity model, as well as validate the truck traffic assignment results.

Based on the above review of data sources, the Global Insight Transearch database stands as a good, though expensive, candidate database for developing a statewide truck network model. Transearch provides OD freight flow estimates at various TAZ levels categorized by commodity type. But, Transearch is not readily available to public. It is proprietary and needs to be purchased. In comparison, FAF2 serves as a no-cost alternative database in case Transearch cannot be purchased. However, FAF2 is a synthetic OD database. FAF2 has synthetic annual average daily truck OD estimates at county level but does not provide commodity flow ODs which can be important in assessing truck types eventually assigned to a network. Thus, total trucks can be modeled using FAF2 but not trucks by various classes. Employment data from employment and security commissions can be used in conjunction recognized truck trip generation rates like those in the QRFM and compared to FAF2 OD data to incorporate any missing trucks.

Table 4 Summary of Data Characteristics and User Agencies for Data Sources

(Sources of the data source indicated under data characteristics.)

Data Sources	**Data Characteristics**	**User Agencies**
Transearch	Scope: Truck shipments of manufactured and selected non-manufactured goods Availability: Reebie Associates (now Global Insight) annual databases since 1980. The detailed county level O-D matrix for base year and also forecasts are available for various prices depending on options requested. http://www.reebie.com/images/transearch.asp#Free%20Motor%20Carrier%20Data%20Exchangez%20Program Data Source: Truck lines and distributors submit their travel data to Reebie and in turn get their market share analysis. Extent: Data available at county, zip code, metropolitan area, state or province level – National Database. Combines information in the Commodity Flow Survey, Railroad Waybill Sample and other public databases.	VDOT Rail & Public Transportation FHWA New York DOT New Jersey DOT Ohio DOT Iowa DOT Kentucky Transportation Cabinet LADOTD
Commodity Flow Survey (CFS)	Scope: Flow of goods and materials by mode of transport. Availability: BTS, USDOT provides the data in the time span 1993- 2002. http://www.bts.gov/publications/commodity_flow_survey/ Data Source: A sample of manufacturing, wholesale and other establishments that complete a questionnaire. Extent: National coverage, stratified by state and metropolitan area.	Oregon DOT Indiana DOT Texas DOT
Transborder Surface Freight	Scope: Freight flow data by commodity type and surface transportation mode for U.S exports to and imports from Canada and Mexico. Availability: BTS, USDOT and Bureau of Census at USDOC. Provides data since April 1993, updated monthly. http://www.bts.gov/ntda/tbscd/prod.html Data Source: Import and export data from administrative records required by Departments of Commerce and Treasury. Extent: All trade entering or leaving US by surface transport to and from Mexico and Canada.	Florida DOT USF Center for Economic Development Research
Freight Analysis Framework (FAF2)	Scope: Annual average daily total truck Ods. Availability: Synthesized by FHWA and available for free. Provided to NCSU prior to release on web. http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm Data Source/Approach: Synthesis from CFS, Transearch and various other data sources. Extent: Data available at county level – National Database.	NCSU/NCDOT

Table 4 (Continued) Summary of Data Characteristics and User Agencies for Data Sources

(Sources of the data source indicated under data characteristics.)

VTRIS	Scope: VTRIS contains categorized annual vehicle traffic data obtained in the field. The data can be obtained for highway links that have a count station. Availability: The VTRIS tables can be obtained for free in the USDOT FHWA web page http://fhwapap07.fhwa.dot.gov/vtris/Default.aspx Data Source: State DOT count stations and databases. Extent: The data can be obtained for many interstate and US routes having count stations.	Florida DOT New Jersey DOT Arizona DOT NCDOT
NCDOT	Scope: NCDOT has hundreds of Automatic Traffic Recorders (ATR's) that count total traffic. Vehicle classification counts are made on a regular basis – approximately every three years. Special short-term classification counts are taken also. NCDOT has 55 Weigh in Motion Stations (WIM's) on Interstates, US and NC highways. WIM's provide annualized, factored, classified counts and weights and they are the basis of VTRIS data. Truck counts are also performed to meet the requirements of the current project based on screen lines, cordon lines and state line. Availability: NCDOT data can be obtained from the Traffic Surveys Unit, VTRIS and HPMS, depending on the location and need for classified or total traffic counts. Extent: Interstates, US and NC routes in North Carolina. VTRIS and HPMS provide counts in neighboring states.	NCDOT
DOT's & MPO's	Scope: Regional model external station surveys, vehicle counts, and origin-destination information. Many regions, cities and towns in NC. Total traffic, percent trucks. Availability: NCDOT, MPO's Extent: Interstates, US and NC routes that cross study area boundaries of urban travel demand models create many external stations.	

Recent Truck Network Model Developments

NCHRP Report 606 reviews the state of the practice of freight activity models. The report addresses statewide, corridor and special generator (port) freight models. It includes a discussion of the national FAF2 model.

Similar to some of the content of the previous literature, NCHRP Report 606 focuses on five model classes:

- Direct facility flow factoring method (regression methods, etc.),
- Origin-destination factoring method (Transearch OD data, FAF OD data),
- Three-step truck model (generation, distribution, assignment),
- Four-step commodity model (generation, distribution, mode split, assignment), and
- Economic activity model (integrated economic/land use forecasts and multimodal commodity demand including generation, distribution, mode split, and assignment)

One important and novel estimation method not covered by NCFRP Report 606 is that developed by List (2002). He synthesized OD flows for New York City based on zonal truck trip generation and attraction and truck ground counts on the NYC network. He used multi-objective math programming to estimate the OD matrix that is most compatible with the ground counts. This method of matrix estimation is different from the existing techniques in that it has high tolerance for inconsistent and sparse observations. List applied the method to vehicles; it can be applied to commodity OD flows as well. The method shows promise in research for single mode and multimodal freight modeling at regional, state and national scales. Recently the NCSU research team applied the method to FAF OD data to achieve NC truck network model assignments that have a high correlation to NCDOT ground counts. Besides truck OD data similar applications could focus on total traffic OD data, or commodities adjustments based on limited flow surveys.

Table 5 shows a summary of the strengths and limitations of the freight models.

The freight models share many of the same components, differing from each other primarily in their organization and use of these components. The review of NCHRP concludes with case studies that illustrate how the models were applied in practice to national multimodal freight and commodity flows, statewide freight models, a metro region, a truck highway corridor, statewide commodity transport, intermodal statewide commodity flows, and heavy truck movements to and from a major seaport.

These models have been applied in a variety of spatial scales – national, statewide, regional, local, corridor and special generator. The choice of model approach depends on how the model will be used to support decision making. Typical needs as illustrated by the cases in NCHRP Report 606 include forecasts for: intermodal freight activity at local or regional scales, truck movements in local or statewide corridors, infrastructure needs to support economic development, multimodal freight activity at a port, and intermodal rail and highway movements.

The FAF case is especially interesting because it is multimodal, commodity-based model that provides a comprehensive methodology and source for data to support model development and policy making from the local to national levels (FAF). FAF not only covers domestic freight movements, but major international freight movements as well. The tool has been developed to provide an accurate, comprehensive forecast of commodity flows and freight activity for the analysis years 1998, 2010, and 2020. These forecasts are sensitive to changes in economic conditions, the transportation system, and other factors according to NCHRP Report 606. FAF, therefore, is a likely candidate for application in the NC truck network model. However, FAF is not necessarily compatible with conventional truck network models. For example, units of flow from FAF are annual tons per commodity type. Annual tons are reported for all four major modes in FAF - truck, rail, water, and air. FAF also provides an assignment of the converted tonnage flows for the highway freight component. These flows are represented in the network as daily trucks for each of the forecast years of 1998, 2010, and 2020. The trucks are identified as being commodity-carrying trucks or non-commodity-carrying trucks.

Table 5 Freight Model Comparisons

Model	Strengths	Limitations
Direct facility factoring	Easy to use Regression based time series Multi-variable "All-in-one" format Corridor and mode specific	Not network based No supply/demand, capacity
OD factoring (FAF)	Available national data Convertible to state & local scales from national scale Course spatial data can be refined by local counts and optimal methods Available future forecasts Multimodal commodity flows Multimodal vehicle flows Regularly improved Relatively low cost	Local and state data are pro-prietary or estimated Course spatial structure (CFS districts & counties) Static "snap shorts" of the future Not directly integrated with economic census Not predictive Not seasonal or by hour of day
Three-step method	Predictive model Detailed level of analysis Multimodal commodity flows	Data intensive High data collection or purchase cost Expensive to develop Long development time
Four-step method	Same as three-step Explicit modal split Connects commodities to modes	Same as 3-step method Requires advanced user skills
Economic activity model	Economic & land use data & forecasts integrated with the three- or four-step methods Multi-modal & multi-commodity method Simple factor methods based on historic traffic & freight trends & forecasts of economic activity Applicable to special generator intermodal facilities, corridors, regional, & statewide scales Easy sensitivity of assumed factors Straight forward policy analysis of alternative modal operations & restrictions Uses data from local, state & national sources	Linear relationships between economic activity & freight flow Does not recognize differences in: values of freight output per ton, production per employee, transportation requirements per ton, or competition among facilities & modes.
Synthetic OD estimation	Compatible with all methods Compatible with all modes Optimizes the use of available validation data Low cost. Acceptable level of estimates in case no flow data are available	Requires advanced user skills Not predictive Poor synthetic estimates lead to poor traffic/commodity assignments

Before using FAF for a truck model adjustments are needed for the following issues. The ones marked with an asterisk * have been addressed and implemented within the NCSU NC truck network model. Other adjustments are needed for multimodal models and for including energy and emissions estimates:

- integration of FAF with a statewide model, truck *
- inclusion of rail and waterborne freight activity,
- flow validation (loaded, unloaded, line haul, back haul), truck*
- truck network flow validation by vehicle class and highway classification, *
- truck freight flow validation by commodity type,
- network validation, truck*
- study area descriptions (BEA, CFS, county, and TAZ employment by industry type and population), *
- estimates of short haul (< 150 miles) truck freight movements, *
- estimates of intra-county short haul truck freight movements, *
- estimates of intra-county short haul truck freight movements by commodity type,
- integration of models and data with GIS tools and TransCAD, *
- integration of statewide model with FAF OD data, truck *
- OD adjustments with TransCAD, truck and total vehicles *
- multimodal and single mode FAF OD data disaggregation, truck*
- FAF OD data rectification versus ground counts, truck and total vehicles*
- energy estimates at the county and intra-county level,
- emissions estimates at the county and intra-county level, total vehicles and individual trucks *
- integration of statewide freight estimates with traditional metro-regional transportation planning models.

Data Requirements for a Truck Network Model

Table 6 summarizes ideal data needs for developing and validating the freight models. Quality and precision are the keys to freight modeling, with the accuracy of the freight flow forecast dependent on the accuracy of the database. If the underlying database is not complete and correct, then the estimated freight flow will be inaccurate (NCHRP Report 606). Generally speaking the data and sources for the highway truck freight are more numerous and developed than for rail and waterborne commerce. This results from truck being the ubiquitous freight mode and the current emphasis on highway truck models at the state and federal levels.

Table 6 Summary of Ideal Data Needs for Different Types of Freight Models

Model	Ideal Data Needs
Direct facility factoring	Traffic and commodity flow counts by year
OD factoring (FAF)	FHWA data available for use, not development Disaggregated spatial structure from CFS districts to counties and TAZs National & state level multimodal networks & attributes Employment, population & economic (BEA) data Commodity mode split; commodity to vehicle loading
Three-step Model	Travel survey data, goods movement data, extensive classification count data, employment data by category type, special truck generators, weigh station data, truck inventory, extensive network data, and trip length distribution.
Four-step Model	All of the same data plus additional survey data, railway data, and roadway attribute data.
Commodity Flow Model	Goods movement data, population and employment data, coarse network with basic data, trip length distribution minimal classification count data.
Economic Activity Model	Economic data & forecasts (local, state) Land use & industrial classifications (current, future) Multi-modal & multi-commodity traffic & freight trends
Synthetic Models	Base year OD matrix: trucks, vehicles or freight data Network with attribute data

Chapter Summary

The literature review presented in this chapter discussed various available modeling approaches and data sources for truck network modeling in North Carolina. A review of other statewide truck models and data sources was also conducted. Urban network models and corridor models discussed in the literature review are not suitable for statewide modeling because of their limited scope and hence can be ruled out as being candidate models. The most frequently used model by state DOTs is the commodity flow model. The dataset used in most statewide freight models is the proprietary Global Insight Transearch data. The Global Insight Transearch database provides OD commodity flows categorized by commodity type. Hence, the commodity flow model is recommended for a statewide truck network model if Transearch data is available.

Alternatively, if funds are not available to purchase Transearch data, a synthetic truck network model using publicly available FAF2 OD annual average daily truck traffic data is feasible at some potential loss in accuracy as the synthetic national data is disaggregated to state TAZs. It is likely that local short haul truck trips are unaccounted for in FAF2 since it is based on fairly large economic districts (four for NC), it is a national database, and it is synthesized from various datasets. Statewide employment data may be useable in conjunction with QRFM trip generation rates to account for ‘missing’ local short haul trips that are not covered in FAF2 data. The Fratar growth factor method has been used in practice to establish rough estimates of statewide growth. Many statewide models used gravity model to distribute the local trips. An all-or-nothing assignment technique is widely used in statewide models to preload trucks in conjunction with subsequent automobile and light truck traffic loadings, whereas the static equilibrium assignment technique is recommended if truck and passenger vehicles are loaded together. Regardless of what method and data are used to develop a statewide truck network model, statewide truck traffic count data must be collected by the DOT to validate base year truck network flows and calibrate the model parameters such as network impedances and assignment algorithm parameters, gravity model parameters, and trip generation rates used to estimate local truck traffic.

Based on the literature review presented in this second chapter, the next chapter describes the synthetic hybrid methodology that is constructed and implemented to develop the North Carolina truck network model.

CHAPTER 3 METHODOLOGY

This chapter presents a discussion of the methodology chosen for developing a prototype North Carolina truck network model based on the literature review and available data. This methodology chapter succinctly describes the steps of the modeling process and focuses on Traffic Analysis Zone (TAZ) and network development. This chapter also raises several issues regarding the methodology with analytical justification. Subsequent chapters and appendices describe the analytical steps involved in the model, statistical tests and results in detail.

Methodology Overview

Figure 5 is a flowchart of the North Carolina truck network model methodology. Summary methodological steps are described below. Please see Chapter 4 and related appendices for the implementation of the methodology.

The model is developed using TransCAD software. The network is based on the National Highway Planning Network (http://www.fhwa.dot.gov/planning/nhpn/). The TAZs are selected such that they cover the entire US concentrating more on North Carolina. The model has more TAZs in urban areas which are expected to be major contributors to truck traffic in North Carolina. The base year for the model is 2006. The model is based on available synthetic FAF2 US county-county OD annual average daily truck traffic (AADTT) flow data and North Carolina employment data (NCESC, 2004). The FAF2 county-county OD AADTT flows are converted into TAZ-TAZ OD AADTT flows by disaggregating FAF2 OD flows for metro TAZs and aggregating FAF2 flows for external US Bureau of Economic Analysis (BEA) TAZs. County to county TAZ OD flows in North Carolina and the external buffer area need no adjustments.

FAF2 is a synthesized nationwide database and it ignores some local short haul truck trips; hence, the methodology includes a method to incorporate these trips that are not covered by FAF2. Productions and attractions of these trips are estimated based on North Carolina employment data. A gravity model is employed and calibrated to estimate short haul truck OD flows in North Carolina. A network assignment of FAF2 ADTT OD flows and short haul ADTT OD flows is then performed using multi-path stochastic assignment technique, which employs Robert Dial's algorithm. Since the model does not include automobile trips and truck-only traffic is usually far below roadway capacity, capacity-constrained traffic assignment techniques, such as User Equilibrium, are not used.

Delineation of TAZs

The model comprises a total of 357 TAZs. The TAZs are developed such that they cover the entire US but they concentrate more in North Carolina. The TAZs can be broadly categorized into internal TAZs, buffer TAZs, and external TAZs, according to their locations relative to North Carolina. Figure 6 illustrates the internal and buffer TAZs. Figure 7 illustrates the internal, buffer and external TAZs. Appendix A gives the TAZ IDs, names, areas and descriptions.

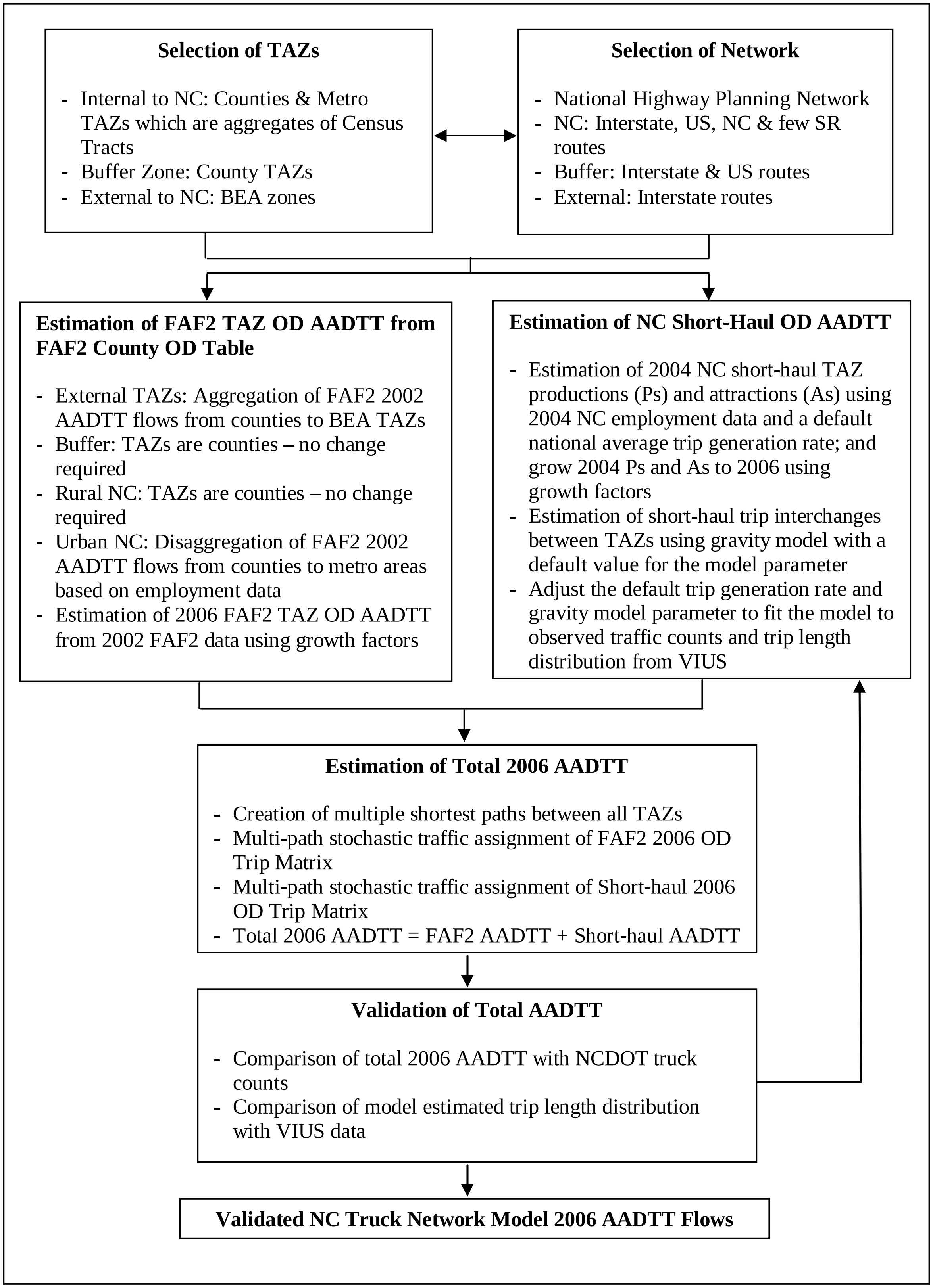

Figure 5 North Carolina Truck Network Model Flowchart

Internal NC TAZs

The methodology divides North Carolina into 139 TAZs. In the rural areas, there are 88 counties as TAZs. In the urban areas the counties are divided into smaller metro geographic TAZs. The 12 NC metro counties contain 51 TAZs. The metro counties are Gastonia, Mecklenburg, Cabarrus, Rowan, Davidson, Forsyth, Guilford, Alamance, Orange, Durham, Wake, Brunswick and New Hanover. The rules for developing metro TAZs are:

- Major routes (Interstates/ US routes) are often boundaries of TAZs.
- Census tracts in urban areas are aggregated into TAZs, and no TAZ boundary cuts through census tracts.
- It is convenient to have natural features as TAZ boundaries.
- Except for Charlotte, downtown areas are separate TAZs. Charlotte's large area has several TAZs.

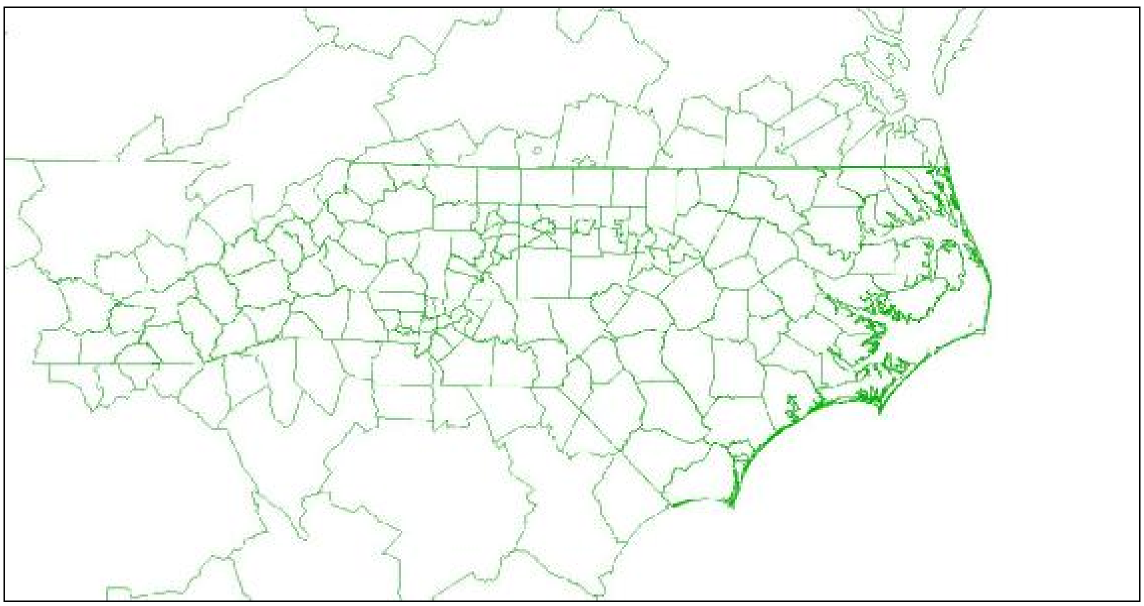

Figure 6 North Carolina Truck Network Model Internal and Buffer TAZs

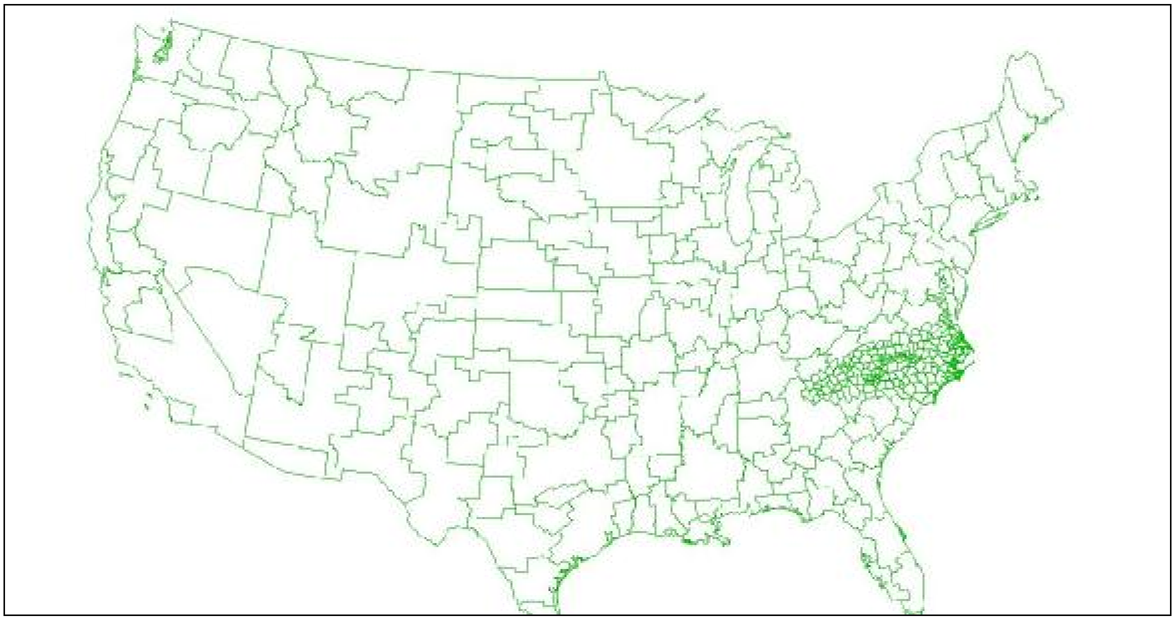

Figure 7 North Carolina Truck Network Model Internal, Buffer and External TAZs

This approach for defining internal TAZs based on census tracts and jurisdictional boundaries is sufficient for this prototype modeling effort. Future refinements may include linkage to Piedmont Crescent MPO models which are also based on census tracts.

Buffer TAZs

Around North Carolina the TAZ geography has a buffer area of counties in neighboring states. The buffer area permits truck drivers to take alternate routes into and out of North Carolina. This allows a smooth transition between the NC study area and the external BEA zones and US network.

Coupled with the external network the buffer area concept is a significant feature of the model because it permits dispersion of external truck traffic into the wider US network. The alternative would be conventional external stations at the North Carolina state border. Such “point source” TAZs would obscure important external truck traffic flow issues that affect North Carolina truck traffic. For example, a seaside or inland freight terminal in Virginia may affect North Carolina truck traffic. Similarly, the effects of significant network changes in neighboring states could be assessed more easily as a result of the buffer concept.

External TAZs

Since the model is a nationwide model concentrating on NC, there are external TAZs at a more aggregate level. The US is divided into 176 TAZs which are Bureau of Economic Analysis (BEA) districts. BEA districts serve as external TAZs to standardize the geography and to link the geography to aggregate census estimates of socioeconomic data such as employment and economic growth.

Having external zones which cover the entire US will improve the flow and distribution of through truck traffic in the North Carolina truck network model. Future refinements to the external TAZs could include smaller sizes and external stations at US ports of entry and border crossings.

Model Network

To be consistent with FAF2 data and modeling efforts by FHWA the network model uses the 2005 version of the National Highway Planning Network for modeling the truck flows in North Carolina. NCDOT uses the National Highway System (NHS) which is very similar to the NHPN but has more local roads. However, this research uses NHPN as it is nationwide and it allows for extending the model across North Carolina. The NHPN consists of Interstate, US highways and 'other' routes. The density of NHPN is consistent with the geography of TAZs in the study area. The road network inside North Carolina consists of all the roads classified under NHPN including Interstates, US, and some NC and SR routes. Outside North Carolina, the network models Interstate highways to capture the traffic to and from external zones. The buffer area allows for the transition in the road network from all NHPN roads inside North Carolina to Interstate highways outside North Carolina. All the NC routes at the state line are extended beyond the state using state routes in the neighboring states and connected to the nearest US or Interstate highway. This made sure there are no dead ends at the state line. All the US routes are terminated near the buffer boundary by appropriately connecting them to the nearest Interstate highway. Figure 8 illustrates the North Carolina network overlaid on the model TAZs. Figure 9 illustrates the national network with buffer links and NC links overlaid on the model TAZs.

Two issues related to using the NHPN are its relative coarse nature (lack of local roads and streets) and the fact that NCDOT uses the NHS. Both issues can be resolved in future North Carolina truck network models as more network links are added, perhaps by using the NCDOT Universe File and line work.

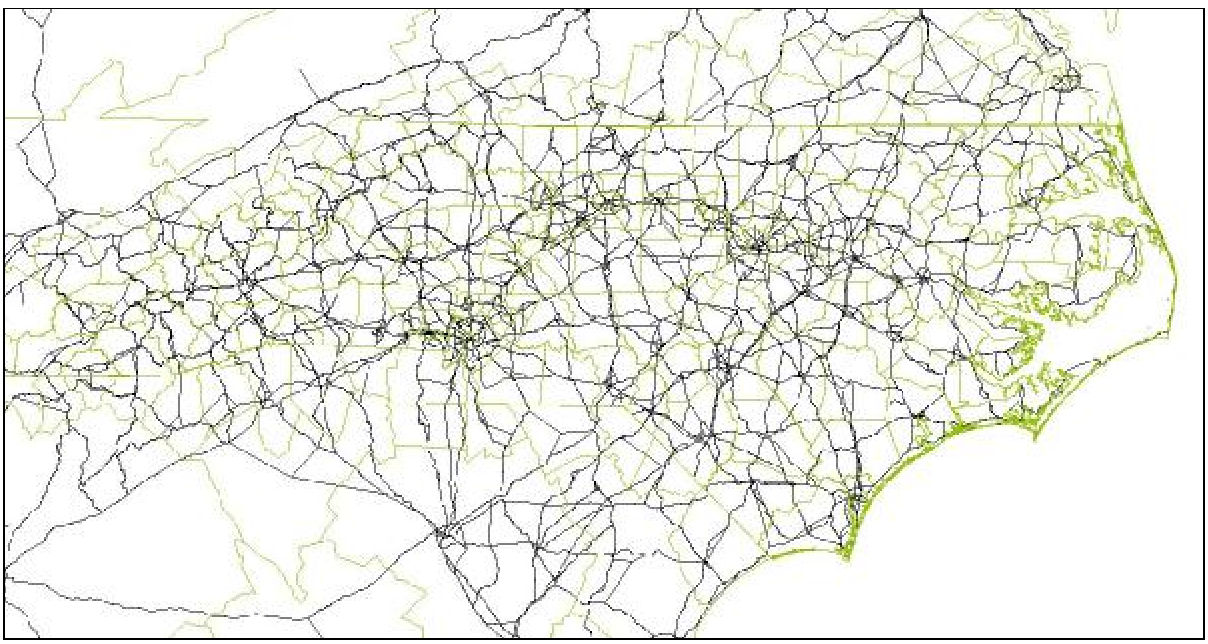

Figure 8 North Carolina Network Overlaid on the Model TAZs

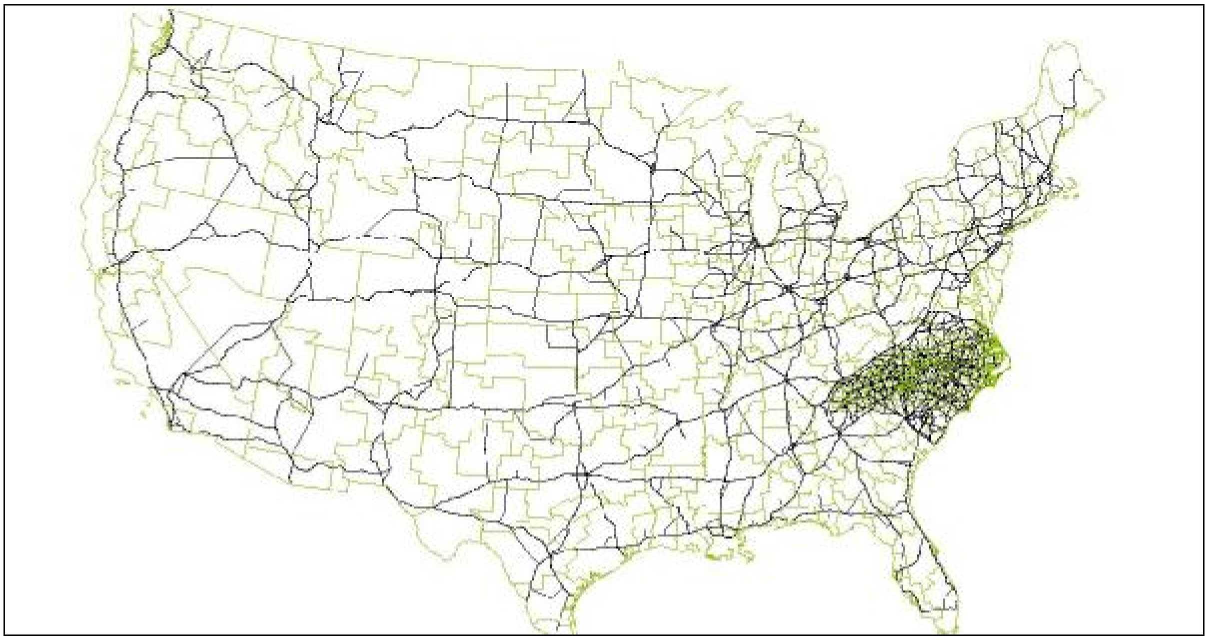

Figure 9 National Network Overlaid on the Model TAZs

Line Layer Connectivity

The network is ready for assignment only if there are no discontinuities. Hence, it is essential to edit the network prior to assignment. The NHPN network is exported from an ArcGIS shapefile to a TransCAD shapefile. The network is then checked for its connectivity in TransCAD. A threshold level of 100 meters is used for checking the connectivity of the network. A total of about 500 errors categorized into three levels indicating the level of discontinuity in the digitized network occurred. The errors generally reflected discontinuities in minor roads and roads terminated at the North Carolina state line. All the errors were manually corrected to make the network ready for assignment.

Future updates to the network should add post-2005 NCDOT highway improvement projects like bypasses and highway widenings (lane additions).

Centroids and Centroid Connectors

To perform the network assignment in TransCAD, all the TAZs have to be associated with a centroid which indicates where the flows to and from a TAZ are centered. All the TAZ flows are thus loaded at the centroids. Centroid connectors are network links which connect a TAZ centroid to the model network. The centroid links may be actual minor roads as in low density county and BEA TAZs, or imaginary links in dense metro TAZs. Centroids and centroid connectors are automatically created using TransCAD. Once all the centroids are ready, centroid IDs are matched to the corresponding TAZ IDs to perform the network assignment.

The automatic TransCAD function for designing centroid connectors is convenient and efficient. It is widely used in practice. For this NC truck network model the "imaginary" centroid connectors formed in the less significant buffer and external zones are likely adequate especially after manual adjustments such as orienting connectors toward US routes or other major highways. Within North Carolina the automatic centroid connector links should be more carefully examined in future research. Issues for consideration include adding known truck routes, including links to large truck generators, and increasing centroid connectors within highly active metro TAZs.

Determination of FFC for Highway Links

To assign reasonable travel speeds to highway links, federal functional classifications (FFC) of the links are required, which differentiate both functionality and area type of the road. It was noticed that the spatial tagging function of ArcGIS didn't produce very reliable FUNCLS (NC functional classes) values for the model network. Therefore, to minimize potential errors, the following approach was used: If the link in NHPN has a value in the FCLASS field, use it directly; otherwise, use the combination of RUPOPU (NC area type) and FUNCLS to impute FFC. Manual corrections were made later where unreasonable FFC values were found.

Average Travel Speed

For assigning the trips using multi-path stochastic assignment technique, link travel speeds are required for all the links in the network. As shown in Table 7, a speed lookup table was developed for assigning a reasonable average travel speed for each highway link based on the functional class, speed limit, number of lanes, and terrain type of the link, as these factors are proven ones having significant impact on speeds. For rural roads, average speeds are pulled directly from the table. However, due to the high abstraction of the urban network in this statewide model, the approach adopted for populating the speed for urban roads is, first pull the speed from the table for an urban link as if it was a rural road, and then factor the speed down based on the classification of the urban link. Values used for these factors are:

- FFC 11 & 12 (interstate freeways and expressways): 0.95
- FFC 14 (urban principal arterials): 0.8
- FFC 16 & 17 (urban minor arterials & collectors): 0.75
- FFC 19 (locals): 0.7

Table 7 Average Travel Speed Lookup Table for NC Truck Network Model

Average Travel Speed		2 lanes									3 lanes or more							
		speed limit (mph)									speed limit (mph)							
Terrain Type	Functional Class	<=20	25	30	35	40	45	50	55	60	30	35	40	45	50	60	65	70
1 (Flat)	1								59	62						60	63	70
	2		30	35	37	42	48	50	53	56	36	40	45	42	54	56	65	
	6		27	31	36	41	46	47	53	56	36	39	44	45	53	56	62	
	7	24	23	30	35	40	44	46	51		34	39	40	40	52	57	60	
	8	21	23	27	34	36	40	41	45		30	33	36	42	47	50		
	9	20	22	24	26	33	36	38	40		27	31	36	33	42	46		
2 (Rolling)	1								53	61						60	63	72
	2		23	31	35	40	45	49	54	59	30	39	44	40	50	50	60	
	6		23	29	34	39	44	47	49	56	33	38	43	43	50	60	61	
	7	22	25	30	30	30	42	46	40		31	33	41	45	49	54	59	
	8	20	22	26	31	34	30	42	44		26	32	36	40	44	46		
	9	20	22	24	20	32	35	37	40		25	29	31	33	40	40		
3 (Mountainous)	1								43	56						57	63	67
	2		29	31	34	36	38	44	48	54	37	39	40	45	48	56	63	
	6		24	26	33	36	38	42	45	53	31	35	38	44	48	53	57	
	7	21	23	27	32	34	37	39	40		30	34	30	40	47	51	53	
	8	19	21	24	30	31	35	38	40		27	31	36	33	42	46		
	9	17	20	22	26	26	32	35	37		26	27	31	34	37	42		

Because the NHPN does not have an attribute for the link speed limits, we used the NCDOT Universe File to find speed limits on various NHPN links inside North Carolina.

Speed limit data for Interstate and US routes outside North Carolina were not available in the Universe File or readily available from other sources. So an assumption of a 55 mi/hr speed limit for trucks on US routes and 70 mi/hr speed for Interstate routes was made for all the non-North Carolina routes.

For all the North Carolina metro TAZs, a speed limit of 35 mi/hr is assumed. For all the centroid connectors in the buffer and North Carolina rural TAZs, a speed limit of 45 mi/hr is assumed. For all the centroid connectors in the BEA zones, a speed limit of 55 mi/hr is assumed.

The approach for setting link speeds is efficient and common practice in national networks that focus on a particular state. However, refinements and other approaches to setting link speed are of interest in future versions of the NC truck network model.

Preparation of FAF2 Data

FAF2 data provided to us by FHWA contains 2002 US county to county AADTT. The data is in the form of a matrix of size 3120*3120 with each of the 3120 rows and columns representing US continental counties. To be consistent with the TAZ structure of the NC truck network model, certain manipulations as described below have to be made first to the original FAF2 OD matrix. The OD flows have to be aggregated or disaggregated based on whether a model TAZ is bigger than a county (e.g. the BEA TAZs) or smaller than a county (e.g. the metro TAZs). Specifically, the following adjustments are made to the original FAF2 OD truck trip matrix:

- Aggregation of trip interchanges for TAZs in the BEA zones
- Disaggregation of trip interchanges for TAZs in North Carolina metro areas

Once the above adjustments are made, the result is a North Carolina truck network model with a 2002 TAZ AADTT OD matrix of size 357*357 with external, buffer and internal TAZs as origins and destinations. Figure 10 represents a thematic of adjusted TAZ AADTT OD matrix. In the figure, 'B' represents buffer TAZs and 'Ex' represents External TAZs.

O\D Trucks		1	2	.	.	88	County	89		.	100	B1	B2	.	B42	Ex1	Ex2	.	Ex176
							Metro TAZ	1	2	.	51								
1																			
2																			
3																			
4																			
.																			
.																			
.																			
88																			
County	Metro TAZ																		
89	1																		
	2																		
	3																		
89	4																		
.	.																		
.	.																		
.																			
100	51																		
B1																			
B2																			
.																			
.																			
.																			
B42																			
Ex1																			
Ex2																			
.																			
.																			
Ex176																			

Figure 10 Thematic Representation of Adjusted TAZ OD AADTT Flow Matrix

The following zone numbers represent the TAZs:

- NC counties: 37001 to 37199
- NC metro TAZs: 370011 to 371999
- Buffer counties in neighboring states: 10000 to 36199 and 38001 to 60199
- BEA TAZs external to NC: 1 to 176

The advantage of making adjustments to the freely available synthetic county level data to convert it into TAZ level data is to avoid excess costs involved in procuring TAZ specific AADTT data from proprietary data sources such as Global Insight Transearch. However, if the future project budgets allow, it is recommended that TAZ specific Transearch data be purchased in the future because adjusting a synthetic OD data involves some level of uncertainty. In addition, the synthetic OD data itself represents a disaggregation of national data to county level OD data.

Aggregation of FAF OD Data

FAF OD AADTT data provide trip interchanges between Os and Ds at the county level for the entire US However, in external zones other than North Carolina, such detailed OD data is not necessary because we are not interested in detailed flow estimates beyond NC. External TAZs are BEA districts; hence, the OD county level data are aggregated to the BEA district level using TransCAD. A correspondence table is developed which shows all the continental US counties that belong to each BEA district. (Appendix B shows a sample of the correspondence table. The entire 65 page document for all 3120 counties and 179 BEAs is available separately.). FAF OD county data is then aggregated to BEA districts using the TransCAD 'Aggregate' tool and the correspondence table.

Disaggregation using North Carolina Employment data

FAF2 OD AADTT data provide truck trip interchanges between Os and Ds at the county level within North Carolina. For the North Carolina truck network model, it is desirable to have Os and Ds at the TAZ level. However, in the North Carolina metro counties, TAZs are at a more disaggregate metro level than the counties. So the OD matrix at the county level has to be suitably disaggregated into a metro TAZ OD matrix. Disaggregation is done based on employment data using TransCAD (Appendix C). The number of employees in a TAZ is estimated by clipping the employment shapefile with each TAZ shapefile. The TAZ shapefile is then populated with an attribute of number of employees based on the results thus obtained from clipping. FAF OD AADTT is then disaggregated from county level to TAZ level using the TransCAD 'Disaggregate' tool with the proportion of zone employment to county employment being the disaggregating factor.

Growing FAF2 Data to Year 2006

The base year for the North Carolina truck network model is 2006; hence, the 2002 FAF2 OD AADTT flows have to be extrapolated to 2006. The year 2000 census provides the average exponential growth factors for each BEA zone based on Gross Domestic Product (GDP) and the factors to extrapolate the 2002 flows to 2006 for each external BEA zone (Appendix D). In North Carolina, the average exponential employment growth factor for each county comes from the period 2002 to 2006 (Appendix E). The factor is used to extrapolate the 2002 FAF2 OD flows for each county pair to 2006.

The TransCAD Fratar procedure is a widely used procedure for OD updating and therefore was employed to grow the original 2002 FAF2 OD matrix. In the process, the 2002 FAF2 matrix was used as a "seed" matrix and the 2006 zonal productions and attractions as control totals.

With respect to using the exponential growth factors, linear growth factors could have been used over the short two and four year periods to growth traffic to the 2006 base year. Differences between linear and exponential growth over the short time period are less than 2%. A detailed analysis of exponential growth factor versus linear growth factor is discussed in Chapter 4.

In future NC truck models for longer forecasts toward the future year 2020 or beyond the more conservative linear growth factor would be more desirable, or using FAF2 OD estimates for the future.

Addition of Empty Truck Trips to the FAF2 Trip Matrix

This section describes in detail how the empty truck trips were added to the FAF2 loaded trip matrix. Specifically, a two-step process was conducted to achieve the resulting trip matrix. The first step adds 30% of the back-haul truck trips to the corresponding "forward-haul" loaded truck trips with an assumption that 30% of the back-haul trucks are empty. While the first step addresses empty trucks, it leaves with us an unbalanced trip matrix as its output where the number of trucks coming out of a zone is not equal to the number of trucks going into the zone on a daily basis. Magnitude of the unbalance could be big or not, all depending on the values in the original FAF2 matrix. But to ensure a balanced trip matrix, a second step had to be conducted. A conventional implementation of the Furness Algorithm directly on the 30%-grown trip matrix did produce a balanced trip matrix where zonal total O's and D's are maintained equal, but some OD pairs were observed with a reduced number of trips which were even lower than the original loaded trips before the 30% back-haul trips added. Considering the nature of the Furness Algorithm being tweaking cell values to match marginals, those big changes in cell values are not abnormal while absolutely not acceptable in our case. After a bit thinking, a fairly creative idea came out, which applies the Furness Algorithm to the growth matrix rather than the grown matrix. This approach can ensure all the cells in the final trip matrix have increased (more or less than 30%) number of trips, while the system-wide increase is maintained at exactly 30%. A full description of the approach is described below.

Step 1: Add Empty Truck Trips

To add 30% of backhaul trips to the original FAF2 trip matrix, the following steps are carried out:
Transpose the original FAF2 matrix;
Multiply the transposed matrix by 30% uniformly; and
Add the 30%-factored matrix to the original FAF2 matrix.

Step 2: Balance Zonal O's and D's

Derive zonal growth targets

From the output matrix of Step 1, compute zonal origin total (O's) and destination total (D's) for each zone. On an average daily basis, the trips in and out of a zone should be equal, i.e., O's = D's. The zonal O's and D's are therefore added together and then divided by 2. This gives the target zonal origin totals and destination totals.

Also compute zonal origin and destination totals (O's and D's) for each zone from the original FAF2 matrix.

Get zonal O's and D's growth targets by subtracting the original O's and D's from the target O's and D's, respectively. The zonal O's and D's growth targets will be used as control totals in the fratar process in step 3) below.

(As a note, two zones were found to have fewer target O's <u>or</u> D's (but not both) than original O's or D's. In this case, the bigger one between O's and D's before averaging is used as the target for both origin and destination totals.)

Derive a trip growth matrix

This matrix is obtained simply by subtracting the original FAF2 matrix from the output matrix of Step 1. This matrix is going to serve as a seed matrix for the fratar process in step 3) below.

Fratar the trip growth matrix

In TransCAD, use the Fratar procedure to balance the trip growth matrix (obtained from step 2) above) with the zonal O's and D's growth targets used as control totals/marginals. The output from this step is a revised trip growth matrix.

Derive a final FAF2 truck trip matrix with empty truck trips included

This matrix is obtained simply by adding the revised trip growth matrix to the original FAF2 matrix.

Since the Fratar process is applied to the growth matrix rather than the base matrix, it is guaranteed that no cells in the final trip matrix (which includes 30% empty truck trips and has balanced zonal O's and D's) have decreased number of trips, compared with the original FAF2 trip matrix.

Estimation of Short Haul Trips

North Carolina Employment Data

North Carolina 2004 employment data were procured from North Carolina Employment and Security Commission (NCESC). The data are given in a text file format and contain about 2.5 million records for all the employers in North Carolina. The data provide information like name of the employer, NAICS code, physical address of the employer, latitude and longitude of the location, and number of employees. TransCAD is used to plot each of the employer locations based on latitude and longitude values. However, some of the records did not have latitude and longitude values. TransCAD tools like plot using zip code and plot using city are used to plot such records. All the sub parts are merged again in TransCAD to obtain the plot of all the employer locations in North Carolina (Figure 11).

As a note, the issue of "headquarters problem" with the North Carolina employment data which centralizes employees according to where their paychecks are issued but not where they actually work was recognized in this research but was not able to be addressed due to the limited data resources.

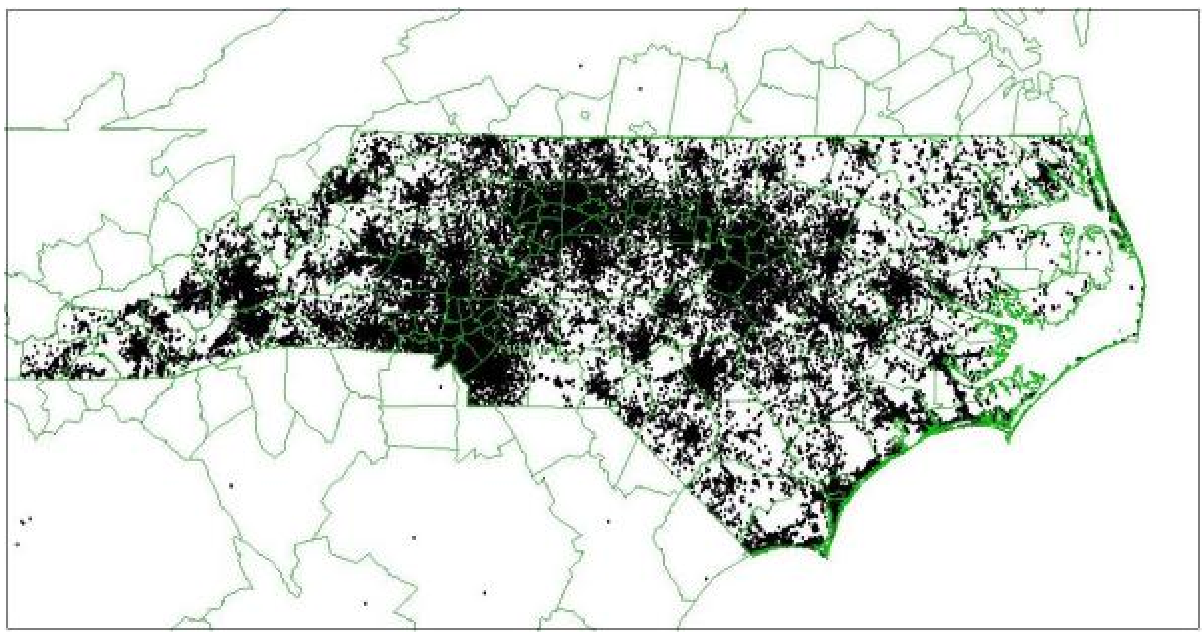

Figure 11 Plot of Employer Locations in North Carolina

Trip Generation

Trip Generation is the process of determining how many trips begin and end in each TAZ based upon zonal socioeconomic data, such as population, employment by industrial classification, and income level. For 2-axle single-unit and heavier truck trips, they are seldom generated by normal residential areas, but mostly by employers. Therefore, employment is used as the explanatory variable for estimating truck trips made by 2-axle single-unit and heavier trucks. Also considering that entire counties are used as TAZs in the model, which generally gives much more balanced land use than smaller geographic units, we therefore do not estimate truck trips based on different employment classifications. Another reason for this is we don't have local survey data to support us to develop different trip rates for different employment types and conduct statistical test on whether different employment type has significantly different trip rate in North Carolina.

For the future, it is recommended that trip generation rates specific to North Carolina be developed by conducting a trip generation study in the state or by borrowing trip generation rates from other states similar to North Carolina.

Trip Distribution

Trip Distribution determines where the trips that are produced in the Trip Generation phase go. It "hooks-up" the trip productions in one TAZ with trip attractions in other TAZs. The gravity model is the most widely used trip distribution model. As its name suggests, the gravity model for transportation planning is based on Newton's gravitational theory. The gravity model predicts that the relative number of trips made between two geographic areas or TAZs, is directly proportional to the number of trip ends (productions and attractions) in each TAZ and inversely proportional to travel impedance (e.g., travel time and/or cost) between those two areas. Modern derivations of the gravity model illustrate that it can be motivated as the most likely spatial arrangement of trips given limited information available on zonal origin totals and constraints about mean trip lengths.

Two typical gravity models used for travel demand modeling are shown below:

$$T_{ij} = P_i \frac{A_j f(d_{ij})}{\sum_z A_z f(d_{iz})} \qquad T_{ij} = A_j \frac{P_i f(d_{ij})}{\sum_z P_z f(d_{zj})}$$

(Constrained to productions) (Constrained to attractions)

Where: T_{ij} = the forecast flow produced by zone *i* and attracted to zone *j*

P_i = the forecast number of trips produced by zone *i*

A_j = the forecast number of trips attracted to zone *j*

d_{ij} = the impedance between zone *i* and zone *j*

$f(d_{ij})$ = the friction factor between zone *i* and zone *j*

As these equations indicate, the gravity model can be singly-constrained to either productions or attractions or doubly-constrained to both productions and attractions. When the model is doubly-constrained, an iterative process is used that alternatively balances the productions from the first equation and then balance the attractions from the second equation. The doubly-constrained model conserves both the zonal productions and attractions. Preferred for the double-conservation ability, a doubly-constrained gravity model was developed in this study for distributing local truck trips.

As widely used in other travel demand models, the exponential function was chosen to compute O-D friction factors based on the travel impedance between each O-D pair. The friction factor has a form as shown below:

$$f(d_{ij}) = e^{-c(d_{ij})}$$

where, c is a parameter that needs to be calibrated in the model. The parameter, c, needs to be calibrated such that the model estimated trip length frequency distributions match the observed (or target) trip length frequency distributions. O-D travel time was used as travel impedance and entered the friction factor function as d_{ij}.

Network Assignment

Stochastic Traffic Assignment

Traffic assignment models are used to estimate the flow of traffic on a network. These models take as input a matrix of flows that indicate the volume of traffic between origin and destination (O-D) pairs. The flows for each O-D pair are loaded onto the network based on the travel time or impedance of the alternative paths that could carry this traffic. TransCAD provides a few traffic assignment procedures, which include All-or-Nothing, Capacity Restraint, User Equilibrium, and Stochastic with and without User Equilibrium assignment methods.

Since modeling of auto trips, which usually account for over 80% of the traffic on highways, are out of the scope of this study, any capacity constrained assignment approach such as the User Equilibrium assignment method was not able to be used for traffic assignment. Of the non-capacity-constrained assignment approaches, the multi-path stochastic assignment method was finally picked in this model for truck traffic assignment. This method uses Robert Dial's algorithm, which distributes trips between O-D pairs among multiple alternative paths that connects the O-D pairs. The proportion of the total trips that is assigned to a particular path equals the choice probability for that path, which is calculated by a logit route choice model. Generally speaking, the smaller the travel time of a path, compared with the travel times of the other paths, the higher its choice probability would be. This method makes more sense than All-or-Nothing assignment where the single shortest path between an O-D pair takes all the trip interchanges for that O-D pair.

FAF2 Truck Trip Assignment

Network assignment of FAF2 trucks involves the estimation of FAF2 truck traffic on each individual link of the highway network. Most statewide models use the all-or-nothing assignment technique to preload trucks and a static equilibrium technique to assign trucks and passenger vehicles together. The North Carolina truck network model does not include the passenger vehicle component. Hence, the multi-path stochastic assignment technique is chosen for assigning the truck trips where all truck trips between an O-D pair get assigned to the few shortest paths.

Short Haul Truck Trip Assignment

Similar to the network assignment of FAF2 2006 ODs, a multi-path stochastic assignment is applied to assign 2006 short haul ADTT OD matrix to the highway network. The total trucks on North Carolina truck network model are then estimated as the sum of FAF2 trucks and short haul truck trips.

Chapter Summary

This chapter discussed the methodology adopted to implement the North Carolina truck network model and to validate the model and its base year traffic estimates. The methodology is based on accepted practices for developing a statewide network model. However, several issues remain to be addressed as the model is developed. The issues include trip generation rates for generating internal short haul truck trips, accurate use of national synthetic data while using it at the state level, trip length distribution calibration, and choice of assignment technique. Some of these issues will be addressed in the subsequent chapter on model calibration and validation.

Several improvements can be made to the model in the future. Future refinements to the TAZs in metro areas may include linkage to Piedmont Crescent MPO models which are based on census tracts. Future refinements to the external TAZs could include smaller sizes and focus on the US ports of entry and border crossings. The density of the network currently chosen can be increased in future models by adding more network links using the NCDOT Universe File. The network in the future models should also be updated with recent NCDOT highway construction projects. The centroid connectors automatically generated using TransCAD should be examined more carefully in future research. The link speed estimates should be improvised in the future based on a function of speed limit, terrain, highway functional class, and traffic volume. If the project budget allows, it is highly recommended that TAZ specific Transearch data be purchased because adjusting a synthetic OD data (FAF2) involves some level of uncertainty. In the future models, alternative truck assignment techniques should be examined for better assignment of the OD ADTT flows.

CHAPTER 4 MODEL CALIBRATION AND VALIDATION RESULTS

Model calibration was accomplished at three levels: system wide, regional level, and link level. System wide calibration was made to make sure model estimated volumes and trip length distribution agree with the observed ones within a reasonable range. Regional level calibration included volume summary comparison at cordon lines and screen lines between the modeled and the observed. Link level calibration included checking and adjusting volumes on major facilities, such as I-85 and I-40, as well as all other classifications of roads. VMT is another important index for model calibration and validation which should be performed at both the system wide level and the regional level.

The model parameters are "tweaked" and adjusted based on the validation results to obtain a validated 2006 North Carolina truck network model. A typical approach follows these steps:

- Conduct reasonableness checks at each stage of the modeling process, as well as after the assignment step.
- Network development (density, coverage, discontinuities, and minimum paths); TAZ development (coverage, number, and consistency of geography with network density). Model calibration adjustments include modeling network and TAZs iteratively such that they are consistent and ready for modeling.
- Trip generation (balance of productions and attractions, average trip rate per employee). Model calibration adjustments include balancing the trip ends and adjusting the trip rates.
- Trip distribution (trip length distributions, control total flow). Model calibration adjustments include adjusting the gravity model parameters.
- Traffic assignment (estimated volumes versus ground counts, screen line balances, VMT). Model calibration adjustments include adjusting speed limits as well as the theta parameter in the assignment model if necessary.

Truck Traffic Ground Count Data

NCDOT conducted a statewide truck traffic count survey in 2006 and 2007 and collected truck trip classification counts at 724 locations across the state, as shown in Figure 12 below. Truck traffic is classified by truck type, which includes bus, 2-, 3-, and 4-axle single-unit, 4-, 5-, and 6-axle single-trailer, and 5-, 6-, and 7-axle multi-trailer. Of these 724 locations, 460 are on the highway links that are represented in the model network. These counts were used as a key element for model calibration and validation.

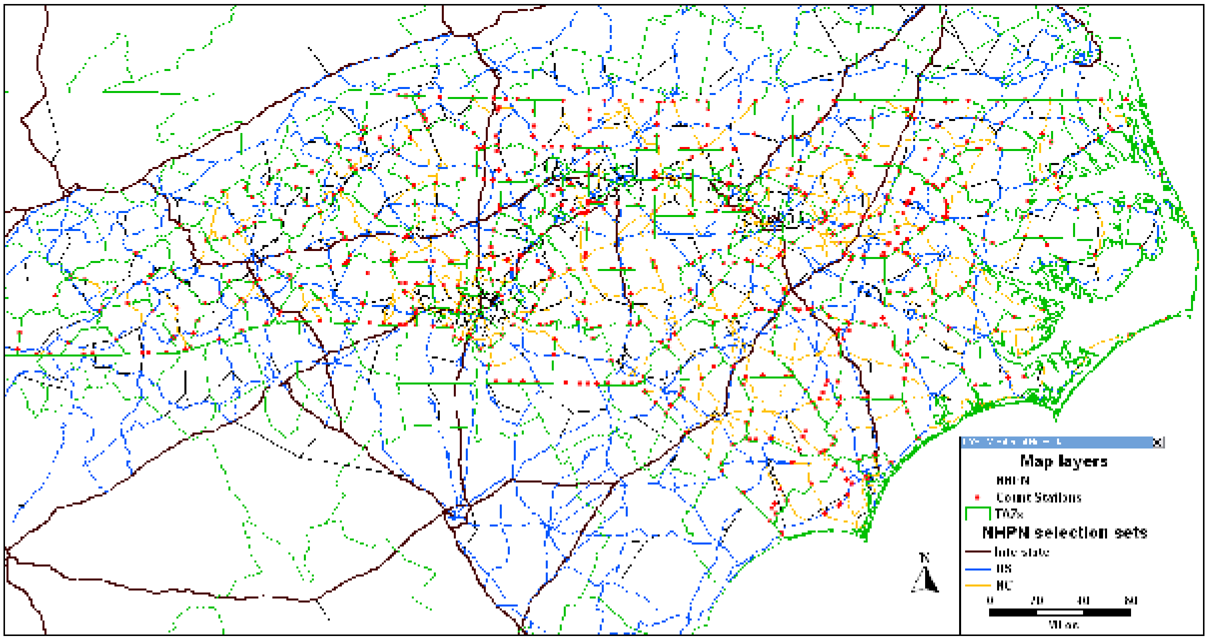

Figure 12 NCDOT Truck Counts overlaid on the Model TAZs and Network

Determination of local truck trip rate and distribution model parameter

With no truck trip survey data available for developing NC-specific trip rates, truck trip rates from other regions were used for reasonableness check when an iteration process was conducted to adjust the trip rate and trip distribution parameters to find the best fit to:

- Ground truck traffic count data; and
- VIUS trip length distribution.

The Vehicle Inventory and Use Survey (VIUS) provides data on the physical and operational characteristics of the nation's private and commercial truck population. Its primary goal is to produce national and state-level estimates of the total number of trucks. This survey was conducted every 5 years, until 2002, as part of the economic census. From the 2002 North Carolina VIUS report, excluding pickups, minivans, other light vans, and sport utilities, the range of operation distribution is as follows.

Table 8 NC VIUS Range of Operation

Range of Operation	VIUS (2002)
50 miles or less	65.5%
51 to 200 miles	25%
201 miles or more	9.5%

As described earlier, the truck trip generation rate and the parameter ***c*** in the exponential function were calibrated together through an iteration process and a value of 0.1 trips per employee and 0.55, respectively, were eventually found to fit the model well to the ground counts as well as the trip distance frequency distribution from VIUS. The calibrated average and median local truck trip lengths are 38 miles and 31 miles, respectively. The frequency distribution is shown in Figure 13.

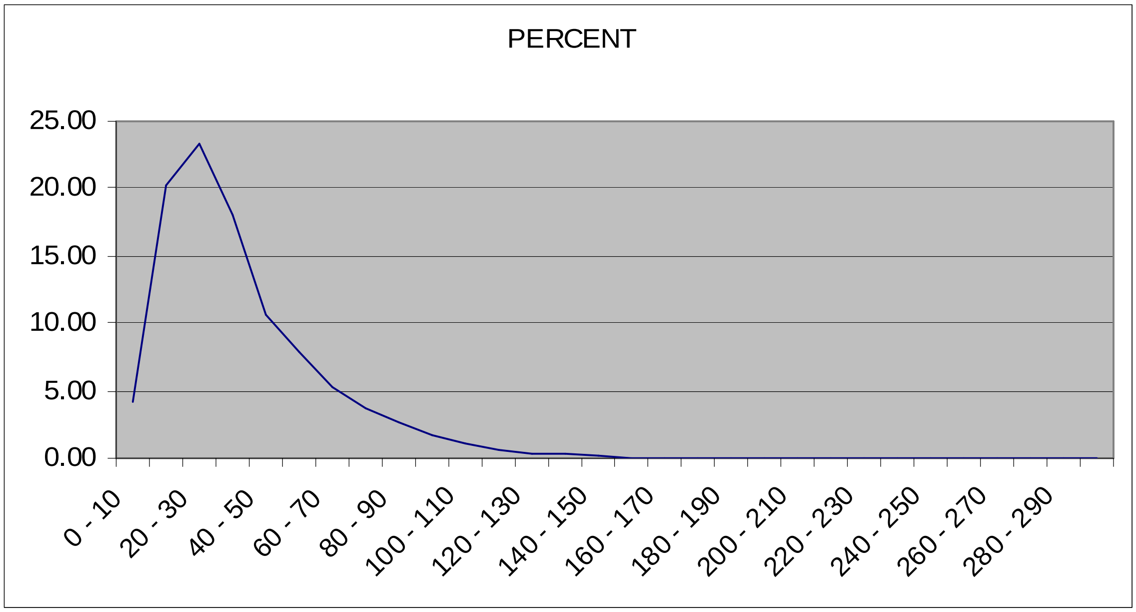

Figure 13 Local Truck Trip Length Frequency Distribution

FAF2 Desire Lines and Trip Length Distribution

While we didn't truly calibrate the FAF2 data except for adding empty truck trips to the original trip matrix, we think it is still a good idea to present some statistics derived from FAF2 data here for the sake of the integrity of the report structure.

FAF2 Desire Lines

Desire lines are usually used to illustrate on a map the flows of people or goods from point to point based on the values from an OD matrix. For example, a matrix could show the number of visitors traveling to a national park from various areas in the country. The width of each of the desire lines would indicate the volume of flow.

Figure 14 illustrates the FAF2 truck flows from (and to) North Carolina to (and from) the rest of the country. As a note, only flows of 100 trips a day or above are displayed in the figure.

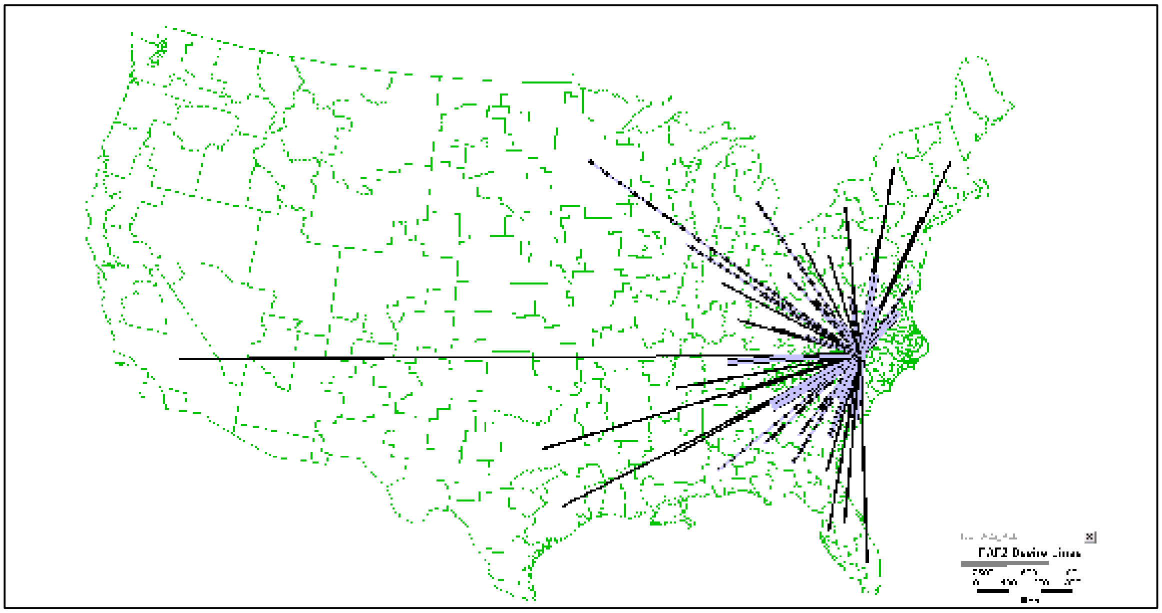

Figure 14 FAF2 Desire Lines from and to NC

The top 10 BEA zones that have the most truck trip interchanges with NC are displayed and highlighted in Figure 15, with their names, major MSAs, and number of daily trips shown in Table 9.

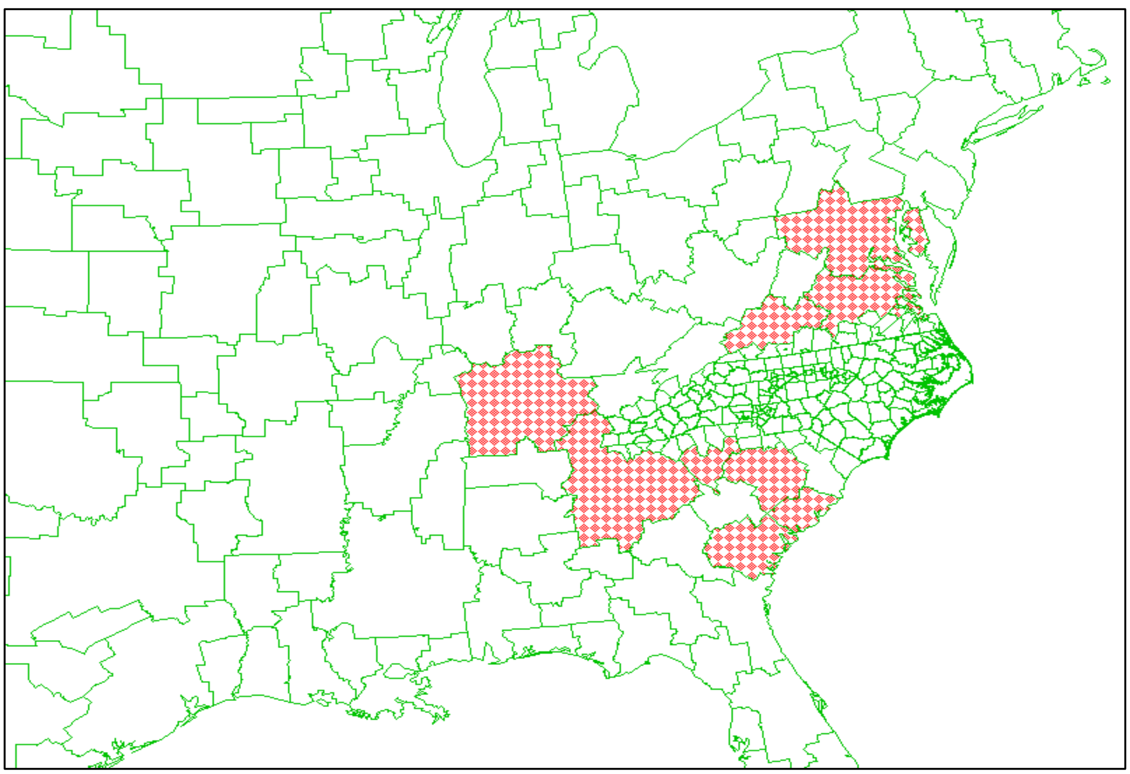

Figure 15 Top 10 BEA Zones with the Most Truck Trip Interchanges with NC

Table 9 Top 10 BEA Zones with the Most Truck Trip Interchanges with NC

BEA Zone	Major MSA(s)	Daily Trips*(2-way)
11	Atlanta-Sandy Springs-Gainesville, GA-AL	4616
38	Columbia-Newberry, SC	4233
30	Charleston - North Charleston, SC	4153
137	Richmond, VA	3620
173	Virginia Beach-Norfolk-Newport News, VA-NC	3105
138	Roanoke, VA	3042
174	Washington-Baltimore-Northern Virginia, DC-MD-VA-WV	2771
68	Greenville-Spartanburg-Anderson, SC	2472
116	Nashville-Davidson-Murfreesboro-Columbia, TN	1984
149	Savannah-Hinesville-Fort Stewart, GA	1912

FAF2 Trip Length Distribution

Excluding all the truck trips that have neither trip origins nor destinations in North Carolina from the FAF2 data, the average and median trip lengths of the trucks that travel from, to, or within NC are 250 miles and 180 miles, respectively. The frequency distribution is shown in Figure 16.

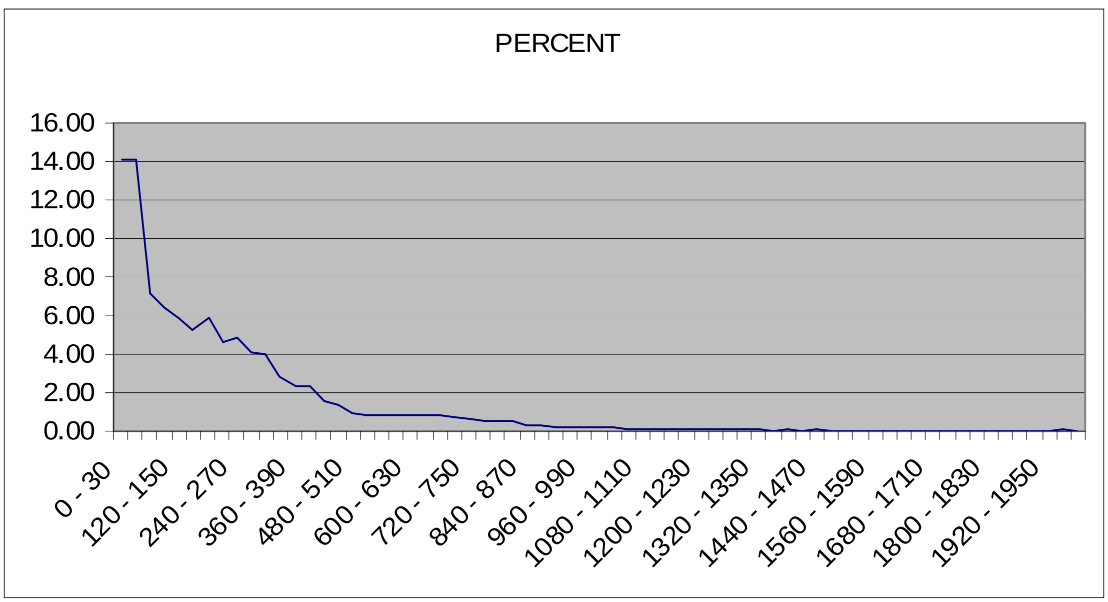

Figure 16 FAF2 Truck Trip Length Distribution

Adjustment of Centroid Connectors and Link-Level Calibration

This process is very important in model calibration. Since we have very big TAZs in the model, the traffic loading could be fairly lumpy if the centroid connectors are not appropriately located and/or the number of centroid connectors is too few. Centroid connectors in the model were reviewed TAZ by TAZ and for all the TAZs, along with link-level traffic assignment calibration. A few centroid connectors were added and many centroid connectors were relocated for better representing the local roads.

Link-level calibration was carried out across the whole state. It tried to improve the model at the very local level so that the model assigned traffic volume on a specific link can get as close as possible to the ground count. As a result of this process, besides centroid connector adjustments, several new highway links were added to the model network, travel speeds on some links were reviewed and adjusted where necessary, and some network connectivity problems were identified and fixed.

K factor: factoring FAF2 and local trips for I-85 and I-40

It was noticed that traffic assignments on I-85 between Charlotte and Greensboro were a bit low, compared with the ground counts, and in contrast the assignments on I-40 between Winston-Salem and Morganton were a bit high (especially between Winston-Salem and I-77). Investigation revealed that the original FAF2 data contribute to the problems: too few on the I-85 segment and too many on I-40. Therefore, K factors were developed to factor down the number of FAF2 trip interchanges for the O-D pairs that use the I-40 segment. Similar things were carried out for I-85 too, but instead of factoring down, trips were factored up in this case as more trips are needed for I-85 between Charlotte and Greensboro. Specifically, the original FAF2 trips in the O-D pairs that use any segment of I-85 between Charlotte and Greensboro were increased by 40%, and the O-D pairs that use any segment of I-40 between I-77 and Greensboro were decreased by 40%.

This brought the traffic on the segment of I-85 to a pretty reasonable level as compared with the count data, but it still didn’t bring enough traffic to the I-40 segment. Being reluctant to increase the FAF2 trips too much, tweaking was done to the local truck trips this time and a 20% increase was applied to the local truck trip O-D pairs that use any segment of I-40 between I-77 and Winston-Salem. Better results were finally achieved for the I-40 segment too.

Model Performance Measures

Calibration efforts were measured by a variety of statistics, primarily including system-wide vehicle miles of travel (VMT), VMT by region, VMT by highway functional class, system-wide percent traffic deviation, percent traffic deviation by highway functional class, percent traffic deviation by screenline, and system-wide coefficient of determination (R-squared). All these statistics were generated by comparing model estimated traffic volumes, average trip lengths, and vehicle miles of travel with observed values. Obviously, the closer the modeled values are to the observed ones, the better the model is.

Scatter Plot – Percent Deviation of Traffic Assignments vs. Counts

The traffic assignment scatter plot shows how close the model estimated traffic assignments are to the ground count data. As shown in Figure 17, the 45^{o} thick line indicates perfect fit where the model estimated value exactly equals the observed one. While a perfect fit is generally impossible, the fact that the dots are scattered closer to the 45^{o} line and more equally on both sides of the line indicates better goodness of fit of the model.

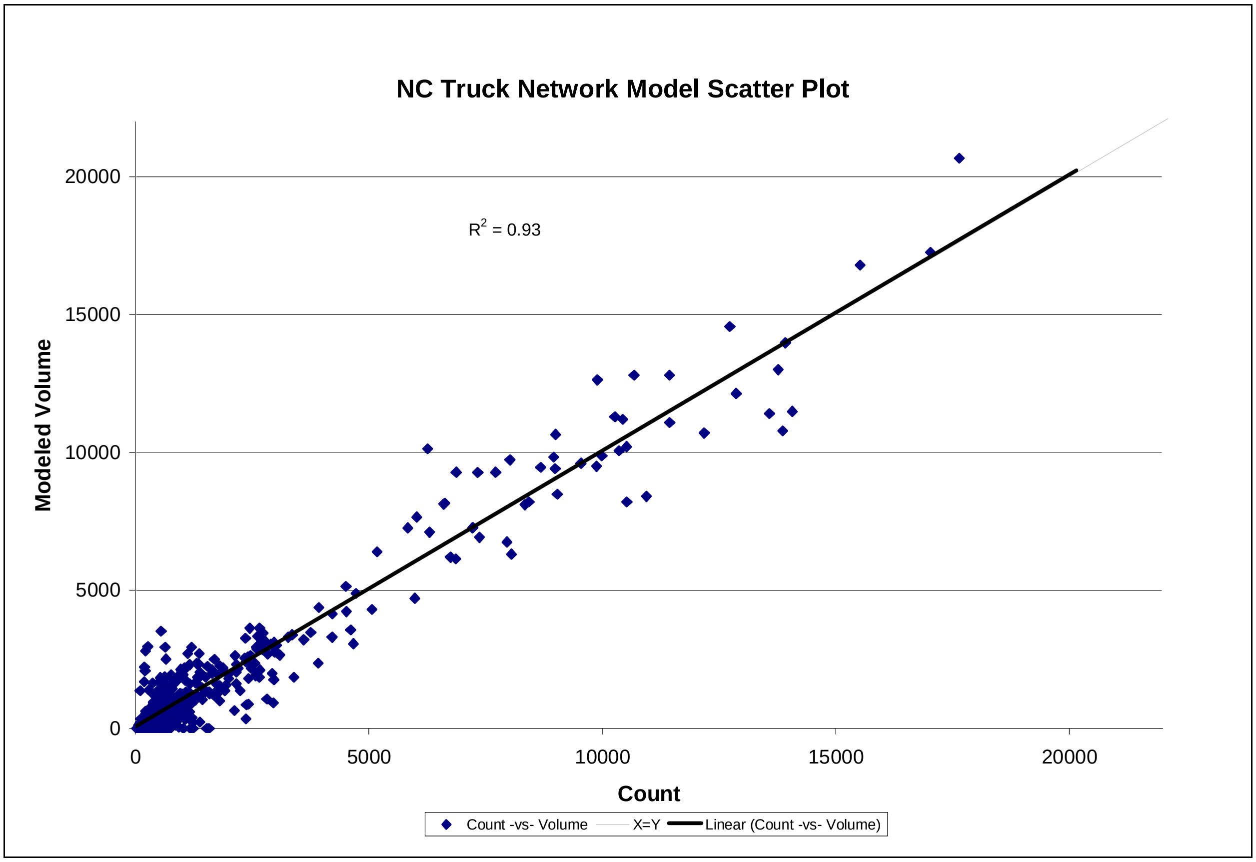

Figure 17 Scatter Plot – Percent Deviation of Assignments vs. Counts

Coefficient of Determination - R-squared

The Coefficient of Determination, i.e. R^2, is another performance index which indicates what proportion of variability in the count data can be explained by the model. Again, a higher R^2 value indicates a better model with 1 for perfect and 0 for random. This model has achieved a R^2 of 0.93, which is even higher than the 0.88 target as indicated in the *Model Validation and Reasonableness Checking Manual* for metropolitan models.

$$r^2 = \left(\frac{n\sum(x_i y_i) - (\sum x_i)(\sum y_i)}{\sqrt{\left[n\sum x_i^2 - (\sum x_i)^2\right]\left[n\sum y_i^2 - (\sum y_i)^2\right]}} \right)^2$$

Trip Length Distribution Comparison

Trip length frequency distribution measures how well the distribution model distributes trips from origins to destinations. Trip length distribution derived from a well-calibrated model should be in good agreement with the observed one. In this model, the VIUS data provide a good data source for calibrating trip distribution model. As shown in the table below, the statistics indicate the model distributes trips well.

Table 10 Trip Length Distribution Comparison

Range of Operation	VIUS (2002)	Model (2006)
50 miles or less	65.5%	68.8%
51 to 200 miles	25%	24.9%
201 miles or more	9.5%	6.3%

VMT Comparison

VMT was computed for the three regions of NC, Costal, Central, and Mountain, as well as the whole state. The statistics are shown in the table below.

Table 11 VMT Comparison Table*

Region	Observed	Modeled	% Deviation
Costal	1,161,953	1,296,132	11.5%
Central	2,460,445	2,478,849	0.7%
Mountain	1,122,541	1,058,764	-5.7%
Total	4,744,938	4,833,745	1.9%

* VMT was computed based on highway links with traffic counts

Screenline / Cordon line Comparison

Seven screen lines and cordon lines were established to intercept major traffic flows throughout the whole state area. Line #1 measures trip interchanges between the coastal area and the rest of the state, and line #2 measures trip interchanges between the mountain area and the rest of the state. Lines #3 - #7 measures trip interchanges between the metropolitan areas of Triangle, Triad, Charlotte, Wilmington, and Ashville and their corresponding outside areas. Assigned traffic volumes in the base year model were compared with the traffic counts at each screenline/ cordon line crossing. The maximum desirable deviation for screenlines used for model calibration was from NCHRP Report 255. The table below summarizes screenline analysis. All percent deviations are below the FHWA recommend maximum desirable percent deviation.

Table 12 Screenline/Cordon Line Summary Table

Screenlines / Cordon Lines	Count	Modeled	% Deviation	% MDD*
#1 - between Costal and Central	23045	26571	15%	+/- 28%
#2 - between Central and Mountain	17355	19195	11%	+/- 30%
#3 - surrounding Triangle	44832	43993	-2%	+/- 21%
#4 - surrounding Triad	49268	45333	-8%	+/- 20%
#5 - surrounding Charlotte	52829	56545	7%	+/- 19%
#6 - surrounding Wilmington	11266	10378	-8%	+/- 35%
#7 - surrounding Ashville	33201	30769	-7%	+/- 25%

* % MDD: FHWA-recommended maximum desirable % deviation

Chapter Summary

This chapter summarizes the calibration and validation efforts conducted for the model. In particular this chapter focuses on determination of local truck trip rate and distribution model parameter, adjustment of centroid connectors, link-level calibration, and development of K factor to address the overestimation and underestimation of traffic flow on I-40 and I-85, respectively. Statistics on performance measures of this model is generated at the end of the chapter, which from different perspectives indicates the model has been calibrated well.

CHAPTER 5 USE OF THE MODEL

Yadkin River Bridge Study

This section reports the results of the application of the truck network model to study the impact of the replacement of the Yadkin River Bridge to traffic operations on I-40 and adjacent roads. The bridge is located on I-40 in Davie County, NC, as shown in Figure 18 and Figure 19. The bridge is actually two independent bridges and each bridge carries two lanes of I-40 traffic – one bridge carries west bound traffic and one bridge carries east bound traffic. The bridges are old and narrow. They need to be replaced. The NCDOT strategy is to replace one bridge at a time and divert traffic to the existing bridge and to a parallel detour route on US 158. For example, when the eastbound lanes and bridge are replaced, the remaining bridge will have one lane for westbound traffic and one lane for eastbound traffic. Some east bound and west bound traffic will likely use the detour route on US 158.

An HCS software analysis suggests that with the work zone in place on I-40, the average travel speed on I-40 in the adjacent sections of the work zone will be 29 mph and the average speed on US-158 will be 34 mph. With these speeds modifying the NC truck network the following results are obtained:

Table 13 Expected Traffic Impacts during the Yadkin River Bridge Replacement

Section	I-40 Traffic Volume Changes	US-158 Traffic Volume Changes
Exit 174 - 180	-3800 trucks/day (-46%)	+1700 trucks per day
Exit 180 - 182	-7080 (-76%)	+4900
Exit 182 - 184	-3700 (-40%)	+1500
East of Exit 184	-2230 (-24%)	+ 50

Note: the "-" sign indicates decrease and "+" indicates increase. The numbers in ( ) are the percent increase or decrease compared with the normal situation. Since there is very little truck traffic on US-158 under normal conditions (less 100 trucks a day), the percent increase of truck traffic on US-158 will be large.

As can be seen from the map (Figure 19), the Yadkin River Bridge is located between Exits 180 and 182; this is where the highest traffic diversion happens according to the table, which is 7080 trucks a day. Diversion decreases with distance from the bridge, which is reasonable and in line with the reality. As expected, US-158 is the road that most of the detouring vehicles take, as it is parallel to I-40 and in its close vicinity. It is also observed that, while US-158 is the road most diverted vehicles take, there are over 1500 trucks which divert to I-85 and US-64, depending on their origins and destinations. The maps below (Figure 20 andFigure 21) can help us visualize the diversion of the truck trips.

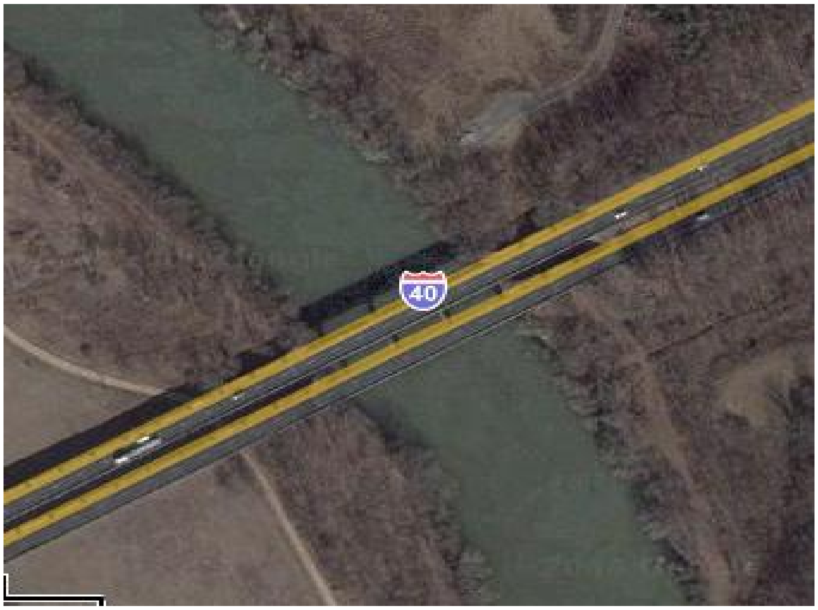

Figure 18 Yadkin River Bridge

Figure 19 Yadkin River Bridge and Adjacent Roads and Communities

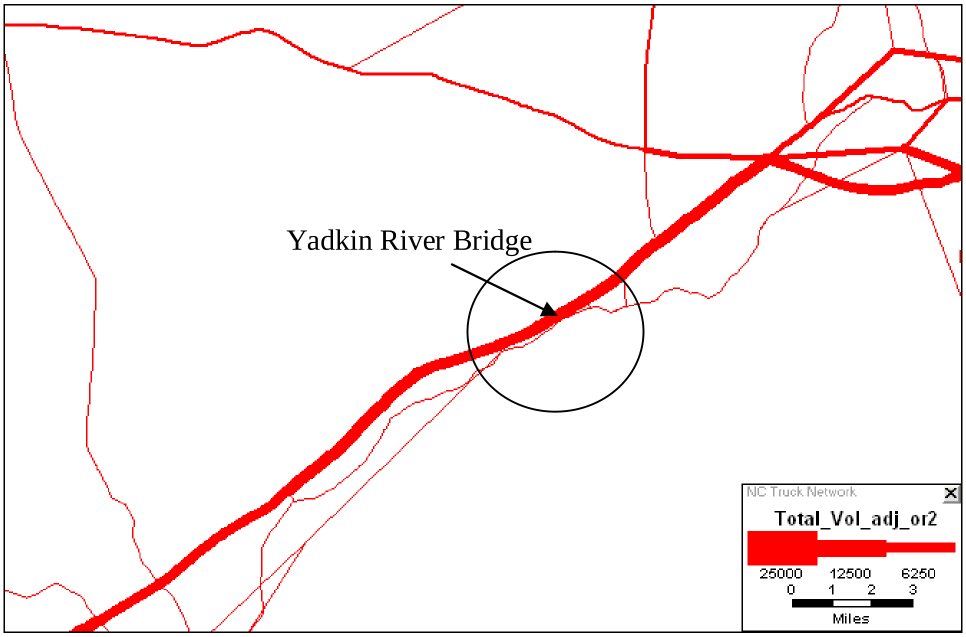

Figure 20 Traffic under Normal Condition

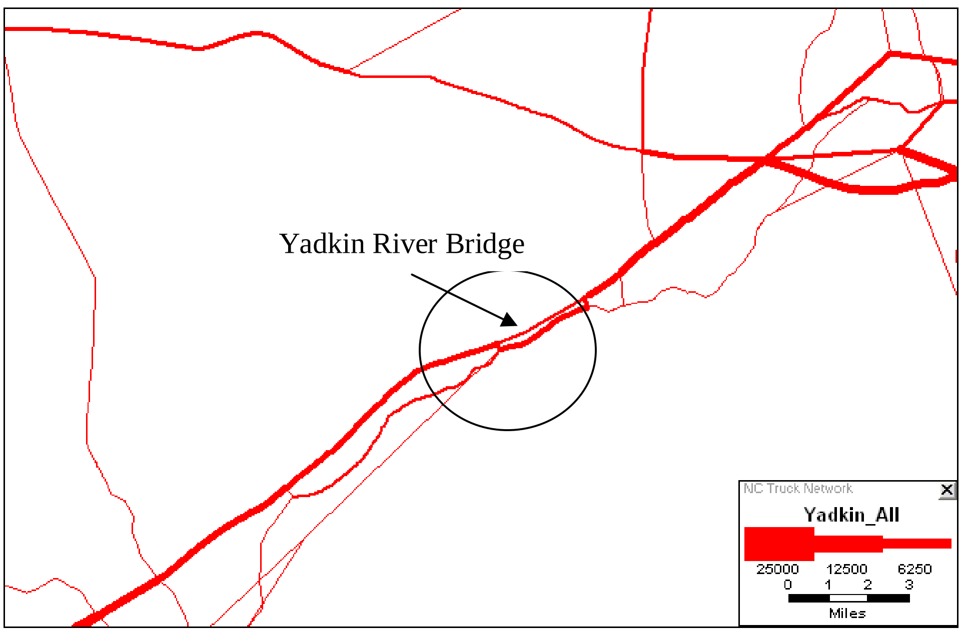

Figure 21 Traffic with Work Zone in Place

Statewide and Regional VMT

Requested by NCDOT, vehicle miles of travel (VMT) were derived from the NC truck network model. Mathematically, VMT is the product of number of vehicles on a highway link and the length of that link in miles. A regional VMT is simply the summation of the VMT's on all the road links in a region, and similarly the VMT of a collective highway functional classification is the summation of the VMT's on all the road links that belong to that classification. As a result, VMT's by region and highway functional classification is summarized in Table 14. As can be seen from the table, the central region produces the most truck VMT's in the state, which is about 13.8 million a day. The coastal and mountain regions make 4.2 and 3.2 million truck VMT's a day, respectively. Assessed at the statewide level but broken down by highway functional class, rural interstate and other principal arterials are the places where the most VMTs take place. They amount to about 6 and 4 million a day, respectively.

Derivation of VMT's for truck types 5 and 9 by region and highway functional classification took a little more work. Due to the lack of region-specific truck type distribution on different types of highways, a statewide distribution table provided by NCDOT was used to derive the VMT's for truck types 5 and 9. The results are shown in Table 15 andTable 16. As a note, since the truck type distribution data are statewide averages, the numbers in the tables may have some bias as the distribution data are applied at a level below the statewide level. Besides similar rows and columns as in Table 15 andTable 16, these two tables each also contain a column titled "%". This column indicates, statewide, what percent of the total VMT on a highway type is made by truck type 5 or 9. For example, truck type 5 accounts for about 10.4% of the total VMT on rural interstate highways, while truck type 9 accounts for 68.6%.

Table 14 VMT by Region and Highway Functional Classification

FFC	Functional Classification	Regional Total Truck VMT			Sub Total
		Central	Costal	Mountain	
1	Rural Principal Arterial - Interstate	3,677,480	1,006,310	1,273,040	5,956,830
2	Rural Principal Arterial - Other	2,077,461	1,399,812	591,434	4,068,707
6	Rural Minor Arterial	1,288,281	669,308	279,991	2,237,580
7	Rural Major Collector	78,887	97,839	38,607	215,333
8	Rural Minor Collector	41,579	25,949	1,712	69,240
9	Rural Local System	73,825	52,097	58,252	184,175
11	Urban Principal Arterial - Interstate	3,114,324	116,599	539,434	3,770,358
12	Urban Principal Arterial - Other Freeways or Expressways	691,733	95,363	32,131	819,227
14	Urban Principal Arterial - Other	1,193,520	391,234	97,605	1,682,359
16	Urban Minor Arterial	42,002	11,692	3,066	56,760
17	Urban Collector	3,756	3,147	322	7,225
19	Urban Local System	1,728	11,216	1,089	14,033
	Centroid Connector	1,544,950	358,678	296,605	2,200,233
Sub Total		**13,829,527**	**4,239,245**	**3,213,288**	**21,282,059**

Table 15 Truck Type-5 VMT by Region and Highway Functional Classification

FFC	Functional Classification	Regional Truck VMT for Type 5 (2ASU)			Sub Total	%
		Central	Costal	Mountain		
1	Rural Principal Arterial - Interstate	383,455	104,929	132,741	621,125	10.4%
2	Rural Principal Arterial - Other	511,069	344,363	145,497	1,000,928	24.6%
6	Rural Minor Arterial	411,671	213,878	89,471	715,019	32.0%
7	Rural Major Collector	33,584	41,652	16,436	91,671	42.6%
8	Rural Minor Collector	20,925	13,059	862	34,846	50.3%
9	Rural Local System	38,040	26,844	30,016	94,900	51.5%
11	Urban Principal Arterial - Interstate	485,948	18,194	84,171	588,313	15.6%
12	Urban Principal Arterial - Other Freeways or Expressways	162,278	22,372	7,538	192,188	23.5%
14	Urban Principal Arterial - Other	426,786	139,900	34,902	601,588	35.8%
16	Urban Minor Arterial	21,343	5,941	1,558	28,842	50.8%
17	Urban Collector	2,078	1,741	178	3,998	55.3%
19	Urban Local System	774	5,022	487	6,284	44.8%
	Centroid Connector	772,475	179,339	148,302	1,100,116	50.0%
Sub Total		**3,270,425**	**1,117,234**	**692,159**	**5,079,819**	**23.9%**

Table 16 Truck Type-9 VMT by Region and Highway Functional Classification

FFC	Functional Classification	Regional Truck VMT for Type 9 (5AST)			Sub Total	%
		Central	Costal	Mountain		
1	Rural Principal Arterial - Interstate	2,524,497	690,807	873,910	4,089,214	68.6%
2	Rural Principal Arterial - Other	962,701	648,677	274,072	1,885,451	46.3%
6	Rural Minor Arterial	477,263	247,955	103,727	828,945	37.0%
7	Rural Major Collector	18,094	22,441	8,855	49,390	22.9%
8	Rural Minor Collector	6,289	3,925	259	10,472	15.1%
9	Rural Local System	5,157	3,639	4,069	12,865	7.0%
11	Urban Principal Arterial - Interstate	1,939,545	72,616	335,950	2,348,111	62.3%
12	Urban Principal Arterial - Other Freeways or Expressways	340,494	46,941	15,816	403,251	49.2%
14	Urban Principal Arterial - Other	374,542	122,774	30,630	527,946	31.4%
16	Urban Minor Arterial	5,062	1,409	369	6,841	12.1%
17	Urban Collector	197	165	17	379	5.2%
19	Urban Local System	137	890	86	1,114	7.9%
	Centroid Connector	108,146	25,107	20,762	154,016	7.0%
Sub Total		**6,762,125**	**1,887,346**	**1,668,523**	**10,317,994**	**48.5%**

CHAPTER 6 FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Findings and Conclusions

The primary objective of this research - to develop a base year truck network model for North Carolina – was accomplished. The validated truck model was used to:
Simulate year 2006 truck flows in and across the state,
Compare the relative magnitudes of North Carolina truck traffic by region (mountains, central, and coastal) and by 12 highway functional classifications including urban and rural interstates, arterials, and local roads,
Identify the relative size of interstate truck flows from North Carolina to major interstate destinations, and
Estimate truck traffic impacts on detour routes resulting from highway and bridge work zones.

The model has particular strengths compared in that it is a statewide model that can be used for:

- Intercity / inter-region travel forecasting,
- Rural area travel forecasting,
- Internal-external travel forecasting for a local North Carolina study area,
- External-external travel forecasting for a local North Carolina study area,
- Internal-internal and external-external travel forecasting for the state of North Carolina,
- Intercity corridor studies,
- Through traffic forecasting for regional MPO models, and
- Specialized projects like commercial vehicle monitoring and truck traffic loading profiles on pavement and bridges.

The development of the NC truck network model relied on no-cost FHWA FAF2 trip matrix data representing long haul truck traffic between US and NC counties. The research demonstrated the feasibility of this approach when combined with NC truck traffic count data, VIUS data, NC employment data, national truck trip data, the National Highway Planning Network and the NCDOT Universe File for highway characteristics. The approach did not use or have available the usual travel modeling survey data: NC truck trip rates by employment type, trip length distributions, time-of-day parameters, truck routing characteristics, etc. Empty trucks and back-haul trips were each assumed to represent 30% of the truck traffic, and local truck trips were based on national truck trip data. This hybrid, synthetic approach (combined with careful modeling skills) yielded a calibrated NC truck trip model that match about 460 ground counts at an R2 of 0.93. Compared to VIUS truck travel estimates, coastal, central and mountain region vehicle miles traveled were +11.5%, +0.7%, and -5.7%, respectively, for an overall total of +1.9%.

Recommendations

Model Applications

The NC truck network model represents a foundation for a statewide highway. Future refinements to the TAZs in metro areas may include linkage to Piedmont Crescent MPO models which are based on census tracts. The Wilmington metro TAZs could be improved by incorporating the proposed port in South Port. Beyond North Carolina the model refinements should include smaller external TAZs and a focus on border crossings to Canada and Mexico, inland destinations, and port destinations for NC truck traffic.

The NC Truck network model also represents a foundation for a statewide multimodal network including passenger vehicles, trucks, rail, air, inland water way, and marine port operations. Estimate freight transportation flows and transfers between modes is a particularly important multimodal issue because of its connection to NC commerce and economic development. Future versions of the model should start with rail connections at inland and marine ports.

Network Improvements

There are several network model issues that should be addressed in the future.

- The NC truck network prototype uses the National Highway Planning Network to be consistent with the FHWA FAF2 data adapted for the research. The NHPN is relatively coarse, and the resulting NC truck network model lacks local roads and streets which are important links for local truck dispatch and deliveries.
- The NCDOT uses the National Highway System (NHS) network.
- The NC truck network model is consistent with the network of highways in 2005.

These issues can be resolved in future North Carolina truck network models as more network links are added, perhaps by using the NCDOT Universe File and line work, to include up-to-date highway improvement projects like bypasses and highway widenings (lane additions).

During network model development within North Carolina the automatic centroid connector function was used to generate centroid connector links. Future model improvements should more carefully examine centroid connectors and include known truck routes, links to large truck generators, and additional centroid connectors within highly active metro TAZs.

Network Link Speeds

Speed limit data for Interstate and US routes outside North Carolina were not available, so an assumption of a 55 mi/hr speed limit for trucks on US routes and a 70 mi/hr speed limit for Interstate routes was made for all the non-North Carolina routes. For all the North Carolina metro TAZs, a speed limit of 35 mi/hr is assumed. For all the centroid connectors in the buffer and North Carolina rural TAZs, a speed limit of 45 mi/hr is assumed. For all the centroid connectors in the BEA zones, a speed limit of 55 mi/hr is assumed. This approach for setting link speeds is efficient and common practice in national networks that focus on a particular state. However, refinements and other approaches to setting link speed are of interest in future versions of the NC truck network model.

Truck Origin-Destination Data

For the NC truck model the following adjustments were made based on employment: (1) aggregation of trip interchanges for TAZs in the BEA zones, and (2) disaggregation of trip interchanges for TAZs in North Carolina metro areas. The result including U.S. BEA zones, buffer counties beyond the NC state line, and NC rural and metro counties was a 357x357 OD matrix for the NC truck network. The advantage of making adjustments to the FHWA FAF2 synthetic OD county data is that it was available at no cost. However adjusting synthetic OD data involves some level of uncertainty. In addition, the synthetic OD data itself represents a disaggregation of national data to county level OD data. Thus, for future projects it is recommended that NC specific Global Insight Transearch data be purchased. Since the cost of the data is expensive, arrangements should be made to share it with other NC state agencies like the NC Department of Commerce, which may already have access to such data.

The current network model and OD flows only estimate truck traffic, yet intermodal connections and flows are vitally important to North Carolina commerce and resulting economic development. Thus, any purchased data should include intermodal flows.

The FHWA FAF multimodal freight methodology continues to be improved every year, and it can be used as a comparative benchmark for any purchased data. If the comparisons are good, future multimodal network models could revert to the no-cost federal database, perhaps refined by operations research tools available at NCSU.

In the event that public domain FAF2 data must be used instead of purchased data, it is recommended that trip generation rates specific to North Carolina be developed by conducting a trip generation study in the state or by borrowing trip generation rates from other states similar to North Carolina.

NC Truck Trip Assignment

The North Carolina truck network model does not include the passenger vehicle component in the total truck assignment (the sum of the FAF2 long haul trucks and the short haul truck trips). Hence, the multi-path stochastic assignment technique is chosen for assigning the truck trips where all truck trips between an O-D pair get assigned to the few shortest paths. The shortest paths are determined by knowing the length of each link and assumed link speeds. Future models should include the passenger car component. Then as most states do for statewide models use the all-or-nothing assignment technique to preload trucks and a static equilibrium technique to assign trucks and passenger vehicles together under capacity constraint. This implies including capacity characteristics to the network in addition to, or in place of, the link speed information currently used.

NC Truck Trip Generation Rates

Short haul truck traffic in North Carolina is estimated based on employment (0.1 truck trips/employee/day). This total average rate does not recognize individual NAICS employment categories. The rate is close to the lower end of the rates reported for some U.S. cities. Because the rate is a state average, it does not explicitly reflect intense truck activity such as that experienced at trucking hubs. This limitation is due to the aggregation of truck activity locations into counties and metropolitan areas, as they serve as traffic analysis zones (TAZs) in this model. Future versions of the model should carefully develop truck trip rates that reflect NAICS employment categories within TAZs.

Future Year Forecasts

The base year for the North Carolina truck network model is 2006. Follow-on efforts must determine extrapolations of the base year model to future year traffic in order to examine future highway deficiencies and test alternative highway improvements. A statewide network model with truck and passenger vehicles will permit such traditional evaluations of:

- traffic flow and safety resulting from bridge and highway improvements,
- traffic diversions and detours,
- freight movements to and from special generators like ports and industry,
- economic impacts on cities and towns, and
- air quality impacts, especially where the statewide model merges with regional models.

A statewide model will also help address contemporary issues such as those posed by the Transportation Research Board in its Fall 2008 solicitation (NCHRP 08-74 [RFP]) for research on DOT performance measures for sustainability. Such measures may be applied ”…at different scales and at different points in system planning and programming; project development, design, construction, and maintenance; and operations”. Such measures may include “…wetland conservation, enhanced economic opportunity, improved air quality, reliable mobility, system preservation, accelerated project delivery, economic vitality, ecosystem services, neighborhood preservation, and increased value of transportation assets. Climate change constitutes an emergent and critical area where agencies need immediate assistance.”

TRB calls for "… achieving the goals of sustainable transportation by developing practical and easy-to-use tools or methods to continuously integrate sustainability into current agency performance measurement programs".

Having a statewide model is another step toward analyzing and achieving a sustainable transportation system.

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APPENDIX A: TAZ ID, NAME, AREA, AND DESCRIPTION

TAZ ID	TAZ Name	Area (sq miles)	Description
1	1: Aberdeen, SD (EA) (57001)	17972.27	External TAZ
2	2: Abilene, TX (EA) (57002)	10871.78	External TAZ
3	3: Albany, GA (EA) (57003)	10351.17	External TAZ
4	4: Albany-Schenectady-Amsterdam, NY (EA) (57004)	10327.10	External TAZ
5	5: Albuquerque, NM (EA) (57005)	20519.61	External TAZ
6	6: Alpena, MI (EA) (57006)	6243.02	External TAZ
7	7: Amarillo, TX (EA) (57007)	36269.64	External TAZ
8	8: Anchorage, AK (EA) (57008)	572938.00	External TAZ
9	9: Appleton-Oshkosh-Neenah, WI (EA) (57009)	6631.98	External TAZ
11	11: Atlanta-Sandy Springs-Gainesville, GA-AL (EA) (57011)	24156.57	External TAZ
12	12: Augusta-Richmond County, GA-SC (EA) (57012)	5530.52	External TAZ
13	13: Austin-Round Rock, TX (EA) (57013)	9565.23	External TAZ
14	14: Bangor, ME (EA) (57014)	18956.88	External TAZ
15	15: Baton Rouge-Pierre Part, LA (EA) (57015)	5257.84	External TAZ
16	16: Beaumont-Port Arthur, TX (EA) (57016)	5111.78	External TAZ
17	17: Bend-Prineville, OR (EA) (57017)	26394.84	External TAZ
18	18: Billings, MT (EA) (57018)	83101.04	External TAZ
19	19: Birmingham-Hoover-Cullman, AL (EA) (57019)	14275.81	External TAZ
20	20: Bismarck, ND (EA) (57020)	28078.77	External TAZ
21	21: Boise City-Nampa, ID (EA) (57021)	31797.41	External TAZ
22	22: Boston-Worcester-Manchester, MA-NH (EA) (57022)	19681.00	External TAZ
23	23: Buffalo-Niagara-Cattaraugus, NY (EA) (57023)	7065.96	External TAZ
24	24: Burlington-South Burlington, VT (EA) (57024)	4830.17	External TAZ
25	25: Cape Girardeau-Jackson, MO-IL (EA) (57025)	7194.74	External TAZ
26	26: Casper, WY (EA) (57026)	75246.29	External TAZ
27	27: Cedar Rapids, IA (EA) (57027)	5838.41	External TAZ
28	28: Champaign-Urbana, IL (EA) (57028)	8459.57	External TAZ
29	29: Charleston, WV (EA) (57029)	16306.92	External TAZ
30	30: Charleston-North Charleston, SC (EA) (57030)	3818.81	External TAZ
31	31: Charlotte-Gastonia-Salisbury, NC-SC (EA) (57031)	591.18	External TAZ
32	32: Chicago-Naperville-Michigan City, IL-IN-WI (EA) (57032)	16228.91	External TAZ
33	33: Cincinnati-Middletown-Wilmington, OH-KY-IN (EA) (57033)	8117.98	External TAZ
34	34: Clarksburg, WV+Morgantown, WV (EA) (57034)	3326.68	External TAZ
35	35: Cleveland-Akron-Elyria, OH (EA) (57035)	10924.58	External TAZ
36	36: Colorado Springs, CO (EA) (57036)	11501.29	External TAZ
37	37: Columbia, MO (EA) (57037)	8800.15	External TAZ
38	38: Columbia-Newberry, SC (EA) (57038)	7756.85	External TAZ

39	39: Columbus-Auburn-Opelika, GA-AL (EA) (57039)	3866.62	External TAZ
40	40: Columbus-Marion-Chillicothe, OH (EA) (57040)	14175.33	External TAZ
41	41: Corpus Christi-Kingsville, TX (EA) (57041)	17240.73	External TAZ
42	42: Dallas-Fort Worth, TX (EA) (57042)	48327.60	External TAZ
43	43: Davenport-Moline-Rock Island, IA-IL (EA) (57043)	3700.79	External TAZ
44	44: Dayton-Springfield-Greenville, OH (EA) (57044)	5685.20	External TAZ
45	45: Denver-Aurora-Boulder, CO (EA) (57045)	73568.91	External TAZ
46	46: Des Moines-Newton-Pella, IA (EA) (57046)	24185.17	External TAZ
47	47: Detroit-Warren-Flint, MI (EA) (57047)	19131.78	External TAZ
48	48: Dothan-Enterprise-Ozark, AL (EA) (57048)	5139.45	External TAZ
49	49: Dover, DE (EA) (57049)	3292.18	External TAZ
50	50: Duluth, MN-WI (EA) (57050)	18928.98	External TAZ
51	51: El Paso, TX (EA) (57051)	35872.90	External TAZ
52	52: Erie, PA (EA) (57052)	4491.98	External TAZ
53	53: Eugene-Springfield, OR (EA) (57053)	15745.97	External TAZ
54	54: Evansville, IN-KY (EA) (57054)	8853.49	External TAZ
55	55: Fargo-Wahpeton, ND-MN (EA) (57055)	17427.16	External TAZ
56	56: Farmington, NM (EA) (57056)	13216.25	External TAZ
57	57: Fayetteville-Springdale-Rogers, AR-MO (EA) (57057)	4590.02	External TAZ
58	58: Flagstaff, AZ (EA) (57058)	22672.78	External TAZ
59	59: Fort Smith, AR-OK (EA) (57059)	6474.78	External TAZ
60	60: Fort Wayne-Huntington-Auburn, IN (EA) (57060)	5151.11	External TAZ
61	61: Fresno-Madera, CA (EA) (57061)	15689.09	External TAZ
62	62: Gainesville, FL (EA) (57062)	5743.77	External TAZ
63	63: Grand Forks, ND-MN (EA) (57063)	20649.92	External TAZ
64	64: Grand Rapids-Muskegon-Holland, MI (EA) (57064)	8597.56	External TAZ
65	65: Great Falls, MT (EA) (57065)	29406.89	External TAZ
66	66: Greensboro-Winston-Salem-High Point, NC (EA) (57066)	50.23	External TAZ
68	68: Greenville-Spartanburg-Anderson, SC (EA) (57068)	3378.92	External TAZ
69	69: Gulfport-Biloxi-Pascagoula, MS (EA) (57069)	2701.91	External TAZ
70	70: Harrisburg-Carlisle-Lebanon, PA (EA) (57070)	8731.81	External TAZ
71	71: Harrisonburg, VA (EA) (57071)	4436.73	External TAZ
72	72: Hartford-West Hartford-Willimantic, CT (EA) (57072)	4660.68	External TAZ
73	73: Helena, MT (EA) (57073)	30352.45	External TAZ
74	74: Honolulu, HI (EA) (57074)	6401.22	External TAZ
75	75: Houston-Baytown-Huntsville, TX (EA) (57075)	31395.30	External TAZ
76	76: Huntsville-Decatur, AL (EA) (57076)	8394.88	External TAZ
77	77: Idaho Falls-Blackfoot, ID (EA) (57077)	26247.50	External TAZ
78	78: Indianapolis-Anderson-Columbus, IN (EA) (57078)	20011.56	External TAZ
79	79: Jacksonville, FL (EA) (57079)	10718.10	External TAZ

80	80: Jackson-Yazoo City, MS (EA) (57080)	33528.23	External TAZ
81	81: Johnson City-Kingsport-Bristol (Tri-Cities), TN-VA (EA) (57081)	6441.74	External TAZ
82	82: Jonesboro, AR (EA) (57082)	5906.67	External TAZ
83	83: Joplin, MO (EA) (57083)	7593.60	External TAZ
84	84: Kansas City-Overland Park-Kansas City, MO-KS (EA) (57084)	25814.34	External TAZ
85	85: Kearney, NE (EA) (57085)	29034.29	External TAZ
86	86: Kennewick-Richland-Pasco, WA (EA) (57086)	9467.69	External TAZ
87	87: Killeen-Temple-Fort Hood, TX (EA) (57087)	6503.49	External TAZ
88	88: Knoxville-Sevierville-La Follette, TN (EA) (57088)	5128.42	External TAZ
89	89: La Crosse, WI-MN (EA) (57089)	4501.71	External TAZ
90	90: Lafayette-Acadiana, LA (EA) (57090)	9500.28	External TAZ
91	91: Lake Charles-Jennings, LA (EA) (57091)	6646.99	External TAZ
92	92: Las Vegas-Paradise-Pahrump, NV (EA) (57092)	62272.96	External TAZ
93	93: Lewiston, ID-WA (EA) (57093)	13625.05	External TAZ
94	94: Lexington-Fayette-Frankfort-Richmond, KY (EA) (57094)	17062.70	External TAZ
95	95: Lincoln, NE (EA) (57095)	7592.64	External TAZ
96	96: Little Rock-North Little Rock-Pine Bluff, AR (EA) (57096)	29576.66	External TAZ
97	97: Los Angeles-Long Beach-Riverside, CA (EA) (57097)	76361.55	External TAZ
98	98: Louisville-Elizabethtown-Scottsburg, KY-IN (EA) (57098)	8501.31	External TAZ
99	99: Lubbock-Levelland, TX (EA) (57099)	16920.67	External TAZ
100	100: Macon-Warner Robins-Fort Valley, GA (EA) (57100)	8637.94	External TAZ
101	101: Madison-Baraboo, WI (EA) (57101)	13862.18	External TAZ
102	102: Marinette, WI-MI (EA) (57102)	16048.28	External TAZ
103	103: Mason City, IA (EA) (57103)	5536.00	External TAZ
104	104: McAllen-Edinburg-Pharr, TX (EA) (57104)	4329.53	External TAZ
105	105: Memphis, TN-MS-AR (EA) (57105)	19469.07	External TAZ
106	106: Miami-Fort Lauderdale-Miami Beach, FL (EA) (57106)	11015.11	External TAZ
107	107: Midland-Odessa, TX (EA) (57107)	48271.02	External TAZ
108	108: Milwaukee-Racine-Waukesha, WI (EA) (57108)	6189.45	External TAZ
109	109: Minneapolis-St. Paul-St. Cloud, MN-WI (EA) (57109)	65766.31	External TAZ
110	110: Minot, ND (EA) (57110)	18895.44	External TAZ
111	111: Missoula, MT (EA) (57111)	19597.95	External TAZ
112	112: Mobile-Daphne-Fairhope, AL (EA) (57112)	9985.18	External TAZ
113	113: Monroe-Bastrop, LA (EA) (57113)	5929.33	External TAZ
114	114: Montgomery-Alexander City, AL (EA) (57114)	8619.78	External TAZ
115	115: Myrtle Beach-Conway-Georgetown, SC (EA) (57115)	3624.74	External TAZ
116	116: Nashville-Davidson-Murfreesboro-Columbia,	22868.22	External TAZ

	TN (EA) (57116)		
117	117: New Orleans-Metairie-Bogalusa, LA (EA) (57117)	8722.24	External TAZ
118	118: New York-Newark-Bridgeport, NY-NJ-CT-PA (EA) (57118)	15284.63	External TAZ
119	119: Oklahoma City-Shawnee, OK (EA) (57119)	46779.84	External TAZ
120	120: Omaha-Council Bluffs-Fremont, NE-IA (EA) (57120)	13331.27	External TAZ
121	121: Orlando-The Villages, FL (EA) (57121)	13366.83	External TAZ
122	122: Paducah, KY-IL (EA) (57122)	3962.40	External TAZ
123	123: Panama City-Lynn Haven, FL (EA) (57123)	3925.04	External TAZ
124	124: Pendleton-Hermiston, OR (EA) (57124)	21015.77	External TAZ
125	125: Pensacola-Ferry Pass-Brent, FL (EA) (57125)	3704.93	External TAZ
126	126: Peoria-Canton, IL (EA) (57126)	11862.50	External TAZ
127	127: Philadelphia-Camden-Vineland, PA-NJ-DE-MD (EA) (57127)	7685.98	External TAZ
128	128: Phoenix-Mesa-Scottsdale, AZ (EA) (57128)	70787.35	External TAZ
129	129: Pittsburgh-New Castle, PA (EA) (57129)	9707.95	External TAZ
130	130: Portland-Lewiston-South Portland, ME (EA) (57130)	13131.36	External TAZ
131	131: Portland-Vancouver-Beaverton, OR-WA (EA) (57131)	21743.26	External TAZ
132	132: Pueblo, CO (EA) (57132)	22014.36	External TAZ
134	133: Raleigh-Durham-Cary, NC (EA) (57133)	36307.97	External TAZ
135	135: Redding, CA (EA) (57135)	23438.96	External TAZ
136	136: Reno-Sparks, NV (EA) (57136)	77567.03	External TAZ
137	137: Richmond, VA (EA) (57137)	9113.53	External TAZ
138	138: Roanoke, VA (EA) (57138)	7263.49	External TAZ
139	139: Rochester-Batavia-Seneca Falls, NY (EA) (57139)	9683.67	External TAZ
140	140: Sacramento-Arden-Arcade-Truckee, CA-NV (EA) (57140)	13704.07	External TAZ
141	141: Salina, KS (EA) (57141)	23172.60	External TAZ
142	142: Salt Lake City-Ogden-Clearfield, UT (EA) (57142)	73216.84	External TAZ
143	143: San Angelo, TX (EA) (57143)	13024.63	External TAZ
144	144: San Antonio, TX (EA) (57144)	28203.89	External TAZ
145	145: San Diego-Carlsbad-San Marcos, CA (EA) (57145)	4270.36	External TAZ
146	146: San Jose-San Francisco-Oakland, CA (EA) (57146)	34614.36	External TAZ
147	147: Santa Fe-Espanola, NM (EA) (57147)	19832.04	External TAZ
148	148: Sarasota-Bradenton-Venice, FL (EA) (57148)	5377.50	External TAZ
149	149: Savannah-Hinesville-Fort Stewart, GA (EA) (57149)	8193.04	External TAZ
150	150: Scotts Bluff, NE (EA) (57150)	15076.38	External TAZ
151	151: Scranton-Wilkes-Barre, PA (EA) (57151)	3353.25	External TAZ
152	152: Seattle-Tacoma-Olympia, WA (EA) (57152)	23291.53	External TAZ
153	153: Shreveport-Bossier City-Minden, LA (EA)	8578.47	External TAZ

	(57153)		
154	154: Sioux City-Vermillion, IA-NE-SD (EA) (57154)	15586.54	External TAZ
155	155: Sioux Falls, SD (EA) (57155)	28044.40	External TAZ
156	156: South Bend-Mishawaka, IN-MI (EA) (57156)	5028.33	External TAZ
157	157: Spokane, WA (EA) (57157)	21505.39	External TAZ
158	158: Springfield, IL (EA) (57158)	9502.09	External TAZ
159	159: Springfield, MO (EA) (57159)	18700.74	External TAZ
160	160: St. Louis-St. Charles-Farmington, MO-IL (EA) (57160)	20209.31	External TAZ
161	161: State College, PA (EA) (57161)	8755.24	External TAZ
162	162: Syracuse-Auburn, NY (EA) (57162)	21531.62	External TAZ
163	163: Tallahassee, FL (EA) (57163)	7581.95	External TAZ
164	164: Tampa-St. Petersburg-Clearwater, FL (EA) (57164)	2613.04	External TAZ
165	165: Texarkana, TX-Texarkana, AR (EA) (57165)	9835.16	External TAZ
166	166: Toledo-Fremont, OH (EA) (57166)	5188.84	External TAZ
167	167: Topeka, KS (EA) (57167)	12744.89	External TAZ
168	168: Traverse City, MI (EA) (57168)	5074.79	External TAZ
169	169: Tucson, AZ (EA) (57169)	16759.36	External TAZ
170	170: Tulsa-Bartlesville, OK (EA) (57170)	15251.44	External TAZ
171	171: Tupelo, MS (EA) (57171)	9589.07	External TAZ
172	172: Twin Falls, ID (EA) (57172)	11434.00	External TAZ
173	173: Virginia Beach-Norfolk-Newport News, VA-NC (EA) (57173)	1064.97	External TAZ
174	174: Washington-Baltimore-Northern Virginia, DC-MD-VA-WV (EA) (57174)	18075.21	External TAZ
175	175: Waterloo-Cedar Falls, IA (EA) (57175)	3431.78	External TAZ
176	176: Wausau-Merrill, WI (EA) (57176)	17569.68	External TAZ
177	177: Wenatchee, WA (EA) (57177)	14837.63	External TAZ
178	178: Wichita Falls, TX (EA) (57178)	10289.17	External TAZ
179	179: Wichita-Winfield, KS (EA) (57179)	35416.74	External TAZ
13111	Fannin County, GA	397.67	Buffer TAZs
13241	Rabun County, GA	385.29	Buffer TAZs
13281	Towns County, GA	182.54	Buffer TAZs
13291	Union County, GA	334.27	Buffer TAZs
37003	Alexander	263.10	NC Rural TAZ
37005	Alleghany	235.45	NC Rural TAZ
37007	Anson	537.17	NC Rural TAZ
37009	Ashe	426.68	NC Rural TAZ
37011	Avery	247.16	NC Rural TAZ
37013	Beaufort	835.62	NC Rural TAZ
37015	Bertie	707.22	NC Rural TAZ
37017	Bladen	887.26	NC Rural TAZ
37019	Brunswick	864.84	NC Rural TAZ
37021	Buncombe	659.76	NC Rural TAZ
37023	Burke	514.84	NC Rural TAZ
37027	Caldwell	474.22	NC Rural TAZ
37029	Camden	241.43	NC Rural TAZ

37031	Carteret	514.13	NC Rural TAZ
37033	Caswell	428.32	NC Rural TAZ
37035	Catawba	413.48	NC Rural TAZ
37037	Chatham	708.98	NC Rural TAZ
37039	Cherokee	466.69	NC Rural TAZ
37041	Chowan	172.98	NC Rural TAZ
37043	Clay	220.61	NC Rural TAZ
37045	Cleveland	468.59	NC Rural TAZ
37047	Columbus	953.82	NC Rural TAZ
37049	Craven	728.53	NC Rural TAZ
37051	Cumberland	658.50	NC Rural TAZ
37053	Currituck	263.36	NC Rural TAZ
37055	Dare	386.57	NC Rural TAZ
37059	Davie	266.85	NC Rural TAZ
37061	Duplin	819.18	NC Rural TAZ
37065	Edgecombe	506.51	NC Rural TAZ
37069	Franklin	494.50	NC Rural TAZ
37073	Gates	343.92	NC Rural TAZ
37075	Graham	301.60	NC Rural TAZ
37077	Granville	536.44	NC Rural TAZ
37079	Greene	265.88	NC Rural TAZ
37083	Halifax	731.19	NC Rural TAZ
37085	Harnett	601.29	NC Rural TAZ
37087	Haywood	554.60	NC Rural TAZ
37089	Henderson	375.04	NC Rural TAZ
37091	Hertford	356.79	NC Rural TAZ
37093	Hoke	392.36	NC Rural TAZ
37095	Hyde	687.39	NC Rural TAZ
37097	Iredell	596.94	NC Rural TAZ
37099	Jackson	494.51	NC Rural TAZ
37101	Johnston	795.76	NC Rural TAZ
37103	Jones	473.35	NC Rural TAZ
37105	Lee	259.32	NC Rural TAZ
37107	Lenoir	402.09	NC Rural TAZ
37109	Lincoln	307.02	NC Rural TAZ
37111	McDowell	446.38	NC Rural TAZ
37113	Macon	519.49	NC Rural TAZ
37115	Madison	451.53	NC Rural TAZ
37117	Martin	461.44	NC Rural TAZ
37121	Mitchell	222.10	NC Rural TAZ
37123	Montgomery	501.63	NC Rural TAZ
37125	Moore	705.67	NC Rural TAZ
37127	Nash	542.61	NC Rural TAZ
37131	Northampton	550.47	NC Rural TAZ
37133	Onslow	768.99	NC Rural TAZ
37137	Pamlico	342.50	NC Rural TAZ
37139	Pasquotank	227.67	NC Rural TAZ
37141	Pender	875.58	NC Rural TAZ

37143	Perquimans	247.89	NC Rural TAZ
37145	Person	403.99	NC Rural TAZ
37147	Pitt	654.73	NC Rural TAZ
37149	Polk	238.60	NC Rural TAZ
37151	Randolph	789.86	NC Rural TAZ
37153	Richmond	479.61	NC Rural TAZ
37155	Robeson	951.17	NC Rural TAZ
37157	Rockingham	572.19	NC Rural TAZ
37161	Rutherford	565.89	NC Rural TAZ
37163	Sampson	947.52	NC Rural TAZ
37165	Scotland	320.68	NC Rural TAZ
37167	Stanly	404.26	NC Rural TAZ
37169	Stokes	455.77	NC Rural TAZ
37171	Surry	537.65	NC Rural TAZ
37173	Swain	540.62	NC Rural TAZ
37175	Transylvania	380.57	NC Rural TAZ
37177	Tyrrell	390.95	NC Rural TAZ
37179	Union	639.47	NC Rural TAZ
37181	Vance	269.76	NC Rural TAZ
37185	Warren	443.69	NC Rural TAZ
37187	Washington	377.21	NC Rural TAZ
37189	Watauga	312.66	NC Rural TAZ
37191	Wayne	556.68	NC Rural TAZ
37193	Wilkes	759.77	NC Rural TAZ
37195	Wilson	374.23	NC Rural TAZ
37197	Yadkin	337.43	NC Rural TAZ
37199	Yancey	313.07	NC Rural TAZ
45021	Cherokee, SC	399.02	Buffer TAZs
45025	Chesterfield, SC	803.41	Buffer TAZs
45033	Dillon, SC	409.17	Buffer TAZs
45045	Greenville, SC	813.28	Buffer TAZs
45051	Horry, SC	1142.38	Buffer TAZs
45057	Lancaster, SC	552.51	Buffer TAZs
45069	Marlboro, SC	493.59	Buffer TAZs
45073	Oconee, SC	683.15	Buffer TAZs
45077	Pickens, SC	502.36	Buffer TAZs
45083	Spartanburg, SC	828.26	Buffer TAZs
45091	York, SC	695.99	Buffer TAZs
47009	Blount, TN	563.22	Buffer TAZs
47019	Carter, TN	353.56	Buffer TAZs
47029	Cocke, TN	447.72	Buffer TAZs
47059	Greene, TN	611.57	Buffer TAZs
47091	Johnson, TN	293.50	Buffer TAZs
47123	Monroe, TN	652.97	Buffer TAZs
47139	Polk, TN	440.07	Buffer TAZs
47155	Sevier, TN	598.55	Buffer TAZs
47171	Unicoi, TN	190.50	Buffer TAZs
51025	Brunswick, VA	570.78	Buffer TAZs

51035	Carroll, VA	480.56	Buffer TAZs
51053	Dinwiddie, VA	505.71	Buffer TAZs
51077	Grayson, VA	441.79	Buffer TAZs
51081	Greensville, VA	285.42	Buffer TAZs
51083	Halifax, VA	835.73	Buffer TAZs
51089	Henry, VA	369.96	Buffer TAZs
51093	Isle of Wight, VA	321.53	Buffer TAZs
51111	Lunenburg, VA	425.94	Buffer TAZs
51117	Mecklenburg, VA	673.48	Buffer TAZs
51141	Patrick, VA	483.48	Buffer TAZs
51143	Pittsylvania, VA	961.84	Buffer TAZs
51175	Southampton, VA	597.05	Buffer TAZs
51183	Sussex, VA	492.92	Buffer TAZs
51550	Chesapeake, VA	339.63	Buffer TAZs
51690	Martinsville, VA	9.02	Buffer TAZs
51800	Suffolk, VA	402.09	Buffer TAZs
51810	Virginia Beach, VA	267.20	Buffer TAZs
370011	Alamance	213.46	NC Urban TAZs
370012	Alamance	62.46	NC Urban TAZs
370013	Alamance	158.78	NC Urban TAZs
370251	Cabarrus	67.97	NC Urban TAZs
370252	Cabarrus	56.77	NC Urban TAZs
370253	Cabarrus	108.80	NC Urban TAZs
370254	Cabarrus	130.26	NC Urban TAZs
370571	Davidson	122.36	NC Urban TAZs
370572	Davidson	127.12	NC Urban TAZs
370573	Davidson	29.50	NC Urban TAZs
370574	Davidson	287.73	NC Urban TAZs
370631	Durham	142.39	NC Urban TAZs
370632	Durham	66.38	NC Urban TAZs
370633	Durham	88.98	NC Urban TAZs
370671	Forsyth	59.53	NC Urban TAZs
370672	Forsyth	122.20	NC Urban TAZs
370673	Forsyth	110.45	NC Urban TAZs
370674	Forsyth	57.54	NC Urban TAZs
370675	Forsyth	63.13	NC Urban TAZs
370711	Gaston	106.23	NC Urban TAZs
370712	Gaston	119.83	NC Urban TAZs
370713	Gaston	30.92	NC Urban TAZs
370714	Gaston	106.57	NC Urban TAZs
370811	Guilford	119.50	NC Urban TAZs
370812	Guilford	183.49	NC Urban TAZs
370813	Guilford	65.95	NC Urban TAZs
370814	Guilford	93.31	NC Urban TAZs
370815	Guilford	89.05	NC Urban TAZs
370816	Guilford	106.29	NC Urban TAZs
371191	Mecklenburg	56.15	NC Urban TAZs
371192	Mecklenburg	47.01	NC Urban TAZs

371193	Mecklenburg	49.53	NC Urban TAZs
371194	Mecklenburg	62.05	NC Urban TAZs
371195	Mecklenburg	89.84	NC Urban TAZs
371196	Mecklenburg	127.18	NC Urban TAZs
371197	Mecklenburg	114.47	NC Urban TAZs
371291	New Hanover	120.65	NC Urban TAZs
371292	New Hanover	58.88	NC Urban TAZs
371293	New Hanover	23.31	NC Urban TAZs
371351	Orange	65.60	NC Urban TAZs
371352	Orange	166.12	NC Urban TAZs
371353	Orange	169.43	NC Urban TAZs
371591	Rowan	128.86	NC Urban TAZs
371592	Rowan	217.26	NC Urban TAZs
371593	Rowan	177.71	NC Urban TAZs
371831	Wake	124.93	NC Urban TAZs
371832	Wake	133.00	NC Urban TAZs
371833	Wake	116.64	NC Urban TAZs
371834	Wake	253.40	NC Urban TAZs
371835	Wake	122.29	NC Urban TAZs
371836	Wake	106.90	NC Urban TAZs

APPENDIX B: COUNTY ID, BEA ID, COUNTY NAME AND BEA NAME

The entire correspondence table for the 3120 US counties and 179 BEA districts takes 65 pages to describe. Thus, this appendix is an abbreviated summary that eliminates many entries and shows samples. Note that only continental counties are included in this model as BEAs, that NC counties are treated separately as entire counties or split into metro TAZs, and that states next to NC (VA, TN, GA and SC) are also dealt with separately as a combination of buffer counties and BEAs. The entire correspondence table is available separately.

County FIPS	BEA Code	County Name, State	BEA Name
01001	114	Autauga County, AL	Montgomery-Alexander City, AL
01003	112	Baldwin County, AL	Mobile-Daphne-Fairhope, AL
01005	48	Barbour County, AL	Dothan-Enterprise-Ozark, AL
01007	19	Bibb County, AL	Birmingham-Hoover-Cullman, AL
01009	19	Blount County, AL	Birmingham-Hoover-Cullman, AL
01011	114	Bullock County, AL	Montgomery-Alexander City, AL
01013	114	Butler County, AL	Montgomery-Alexander City, AL
01015	19	Calhoun County, AL	Birmingham-Hoover-Cullman, AL
. . .			
05011	96	Bradley County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05013	96	Calhoun County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05015	159	Carroll County, AR	Springfield, MO
05059	96	Hot Spring County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05061	165	Howard County, AR	Texarkana, TX-Texarkana, AR
05063	96	Independence County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05065	96	Izard County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05067	96	Jackson County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05069	96	Jefferson County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05071	96	Johnson County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05073	96	Lafayette County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05075	82	Lawrence County, AR	Jonesboro, AR
05077	105	Lee County, AR	Memphis, TN-MS-AR
05079	96	Lincoln County, AR	Little Rock-North Little Rock-Pine Bluff, AR
05081	165	Little River County, AR	Texarkana, TX-Texarkana, AR
05083	59	Logan County, AR	Fort Smith, AR-OK
05085	96	Lonoke County, AR	Little Rock-North Little Rock-Pine Bluff, AR
. . .			
06001	146	Alameda County, CA	San Jose-San Francisco-Oakland, CA
06003	140	Alpine County, CA	Sacramento--Arden-Arcade--Truckee, CA-NV
06005	140	Amador County, CA	Sacramento--Arden-Arcade--Truckee, CA-NV
06007	140	Butte County, CA	Sacramento--Arden-Arcade--Truckee, CA-NV

06009	146	Calaveras County, CA	San Jose-San Francisco-Oakland, CA
06011	140	Colusa County, CA	Sacramento--Arden-Arcade--Truckee, CA-NV
. . .			
30105	18	Valley County, MT	Billings, MT
30109	18	Wibaux County, MT	Billings, MT
30111	18	Yellowstone County, MT	Billings, MT
31001	85	Adams County, NE	Kearney, NE
31003	154	Antelope County, NE	Sioux City-Vermillion, IA-NE-SD
31005	85	Arthur County, NE	Kearney, NE
31007	150	Banner County, NE	Scotts Bluff, NE
31009	85	Blaine County, NE	Kearney, NE
31011	120	Boone County, NE	Omaha-Council Bluffs-Fremont, NE-IA
. . .			
56033	18	Sheridan County, WY	Billings, MT
56035	26	Sublette County, WY	Casper, WY
56037	26	Sweetwater County, WY	Casper, WY
56039	26	Teton County, WY	Casper, WY
56041	26	Uinta County, WY	Casper, WY
56043	26	Washakie County, WY	Casper, WY
56045	26	Weston County, WY	Casper, WY

APPENDIX C: EMPLOYMENT FACTORS FOR DISAGGREGATING OD FLOWS

TAZ ID	EMPLOYMENT	FACTOR
370011	5336	0.085
370012	40715	0.647
370013	16836	0.268
37003	9434	1.000
37005	3716	1.000
37007	7448	1.000
37009	8533	1.000
37011	7334	1.000
37013	16865	1.000
37015	6452	1.000
37017	12658	1.000
37019	25313	1.000
37021	113632	1.000
37023	32285	1.000
370251	15490	0.243
370252	40830	0.642
370253	2408	0.038
370254	4888	0.077
37027	32703	1.000
37029	934	1.000
37031	24001	1.000
37033	2521	1.000
37035	96357	1.000
37037	15679	1.000
37039	8404	1.000
37041	6139	1.000
37043	1914	1.000
37045	38387	1.000
37047	16240	1.000
37049	35630	1.000
37051	111188	1.000
37053	5239	1.000
37055	20114	1.000
370571	4752	0.102
370572	8025	0.173
370523	13417	0.289
370524	20249	0.436
37059	10323	1.000
37061	20757	1.000
370631	19011	0.115
370632	63820	0.386
370633	82436	0.499
37065	21550	1.000
370671	93268	0.514

370672	10094	0.056
370673	11964	0.066
370674	52547	0.289
370675	13713	0.076
37069	10672	1.000
370711	6520	0.092
370712	13804	0.194
370713	40279	0.565
370714	10639	0.149
37073	1556	1.000
37075	2400	1.000
37077	14381	1.000
37079	2792	1.000
370811	42737	0.154
370812	7645	0.028
370813	112206	0.404
370814	88192	0.318
370815	19532	0.070
370816	7370	0.027
37083	18151	1.000
37085	24978	1.000
37087	17057	1.000
37089	36742	1.000
37091	9791	1.000
37093	9216	1.000
37095	1164	1.000
37097	59590	1.000
37099	13578	1.000
37101	41729	1.000
37103	1321	1.000
37105	28857	1.000
37107	27451	1.000
37109	19977	1.000
37111	15786	1.000
37113	10368	1.000
37115	3750	1.000
37117	7853	1.000
371191	14292	0.028
371192	10369	0.021
371193	54740	0.109
371194	20669	0.041
371195	82446	0.163
371196	264323	0.524
371197	57484	0.114
37121	5165	1.000
37123	10363	1.000
37125	32044	1.000
37127	44294	1.000

371291	16749	0.169
371292	31747	0.320
371293	50800	0.512
37131	4893	1.000
37133	39434	1.000
371351	4324	0.076
371352	45168	0.795
371353	7335	0.129
37137	2771	1.000
37139	14557	1.000
37141	9441	1.000
37143	2018	1.000
37145	11203	1.000
37147	69322	1.000
37149	4406	1.000
37151	52062	1.000
37153	14589	1.000
37155	38889	1.000
37157	30750	1.000
371591	16808	0.341
371592	27549	0.559
371593	4943	0.100
37161	22804	1.000
37163	18809	1.000
37165	16022	1.000
37167	18402	1.000
37169	6590	1.000
37171	32696	1.000
37173	5602	1.000
37175	7765	1.000
37177	844	1.000
37179	52761	1.000
37181	17009	1.000
371831	12568	0.034
371832	23911	0.065
371833	16496	0.045
371834	46835	0.127
371835	64016	0.173
371836	205204	0.556
37185	3810	1.000
37187	5667	1.000
37189	21261	1.000
37191	42069	1.000
37193	25518	1.000
37195	40810	1.000
37197	8891	1.000
37199	4010	1.000

APPENDIX D: AVERAGE GROWTH FACTORS FOR BEA ZONES BASED ON GDP

BEA ID and Name	AGF
1: Aberdeen, SD (EA) (57001)	1.0612599
2: Abilene, TX (EA) (57002)	1.063823
3: Albany, GA (EA) (57003)	1.0480562
4: Albany-Schenectady-Amsterdam, NY (EA) (57004)	1.0436531
5: Albuquerque, NM (EA) (57005)	1.063783
6: Alpena, MI (EA) (57006)	1.0223173
7: Amarillo, TX (EA) (57007)	1.0638141
8: Anchorage, AK (EA) (57008)	1.0790661
9: Appleton-Oshkosh-Neenah, WI (EA) (57009)	1.0424635
10: Asheville-Brevard, NC (EA) (57010)	1.0489738
11: Atlanta-Sandy Springs-Gainesville, GA-AL (EA) (57011)	1.0477498
12: Augusta-Richmond County, GA-SC (EA) (57012)	1.0455706
13: Austin-Round Rock, TX (EA) (57013)	1.063823
14: Bangor, ME (EA) (57014)	1.0482784
15: Baton Rouge-Pierre Part, LA (EA) (57015)	1.0508193
16: Beaumont-Port Arthur, TX (EA) (57016)	1.063823
17: Bend-Prineville, OR (EA) (57017)	1.0520388
18: Billings, MT (EA) (57018)	1.0727478
19: Birmingham-Hoover-Cullman, AL (EA) (57019)	1.0577604
20: Bismarck, ND (EA) (57020)	1.0652198
21: Boise City-Nampa, ID (EA) (57021)	1.0614899
22: Boston-Worcester-Manchester, MA-NH (EA) (57022)	1.0456598
23: Buffalo-Niagara-Cattaraugus, NY (EA) (57023)	1.0439163
24: Burlington-South Burlington, VT (EA) (57024)	1.0534509
25: Cape Girardeau-Jackson, MO-IL (EA) (57025)	1.0406462
26: Casper, WY (EA) (57026)	1.0916423
27: Cedar Rapids, IA (EA) (57027)	1.0473558
28: Champaign-Urbana, IL (EA) (57028)	1.0383157
29: Charleston, WV (EA) (57029)	1.0491077
30: Charleston-North Charleston, SC (EA) (57030)	1.0447738
31: Charlotte-Gastonia-Salisbury, NC-SC (EA) (57031)	1.047718
32: Chicago-Naperville-Michigan City, IL-IN-WI (EA) (57032)	1.0391468
33: Cincinnati-Middletown-Wilmington, OH-KY-IN (EA) (57033)	1.0416808
34: Clarksburg, WV+Morgantown, WV (EA) (57034)	1.0505427
35: Cleveland-Akron-Elyria, OH (EA) (57035)	1.0352116
36: Colorado Springs, CO (EA) (57036)	1.0474856
37: Columbia, MO (EA) (57037)	1.0410699
38: Columbia-Newberry, SC (EA) (57038)	1.0447738
39: Columbus-Auburn-Opelika, GA-AL (EA) (57039)	1.0498994
40: Columbus-Marion-Chillicothe, OH (EA) (57040)	1.0352438
41: Corpus Christi-Kingsville, TX (EA) (57041)	1.063823
42: Dallas-Fort Worth, TX (EA) (57042)	1.0637404
43: Davenport-Moline-Rock Island, IA-IL (EA) (57043)	1.041329
44: Dayton-Springfield-Greenville, OH (EA) (57044)	1.0346975

45: Denver-Aurora-Boulder, CO (EA) (57045)	1.0496623
46: Des Moines-Newton-Pella, IA (EA) (57046)	1.0473558
47: Detroit-Warren-Flint, MI (EA) (57047)	1.0223173
48: Dothan-Enterprise-Ozark, AL (EA) (57048)	1.0562865
49: Dover, DE (EA) (57049)	1.0635149
50: Duluth, MN-WI (EA) (57050)	1.0477306
51: El Paso, TX (EA) (57051)	1.0637963
52: Erie, PA (EA) (57052)	1.0465228
53: Eugene-Springfield, OR (EA) (57053)	1.0520388
54: Evansville, IN-KY (EA) (57054)	1.0905747
55: Fargo-Wahpeton, ND-MN (EA) (57055)	1.0623764
56: Farmington, NM (EA) (57056)	1.0498138
57: Fayetteville-Springdale-Rogers, AR-MO (EA) (57057)	1.0546476
58: Flagstaff, AZ (EA) (57058)	1.0629074
59: Fort Smith, AR-OK (EA) (57059)	1.2081655
60: Fort Wayne-Huntington-Auburn, IN (EA) (57060)	1.0404622
61: Fresno-Madera, CA (EA) (57061)	1.0476305
62: Gainesville, FL (EA) (57062)	1.0741463
63: Grand Forks, ND-MN (EA) (57063)	1.058732
64: Grand Rapids-Muskegon-Holland, MI (EA) (57064)	1.0223173
65: Great Falls, MT (EA) (57065)	1.0695334
66: Greensboro-Winston-Salem-High Point, NC (EA) (57066)	1.0520045
67: Greenville, NC (EA) (57067)	1.0484541
68: Greenville-Spartanburg-Anderson, SC (EA) (57068)	1.0450804
69: Gulfport-Biloxi-Pascagoula, MS (EA) (57069)	1.0482376
70: Harrisburg-Carlisle-Lebanon, PA (EA) (57070)	1.0465228
71: Harrisonburg, VA (EA) (57071)	1.0603167
72: Hartford-West Hartford-Willimantic, CT (EA) (57072)	1.0372275
73: Helena, MT (EA) (57073)	1.0695334
74: Honolulu, HI (EA) (57074)	1.0610165
75: Houston-Baytown-Huntsville, TX (EA) (57075)	1.063823
76: Huntsville-Decatur, AL (EA) (57076)	1.0575912
77: Idaho Falls-Blackfoot, ID (EA) (57077)	1.0624351
78: Indianapolis-Anderson-Columbus, IN (EA) (57078)	1.0416757
79: Jacksonville, FL (EA) (57079)	1.0553614
80: Jackson-Yazoo City, MS (EA) (57080)	1.0488113
81: Johnson City-Kingsport-Bristol (Tri-Cities), TN-VA (EA) (57081)	1.0584102
82: Jonesboro, AR (EA) (57082)	1.0510245
83: Joplin, MO (EA) (57083)	1.0474505
84: Kansas City-Overland Park-Kansas City, MO-KS (EA) (57084)	1.0429771
85: Kearney, NE (EA) (57085)	1.0497406
86: Kennewick-Richland-Pasco, WA (EA) (57086)	1.0379954
87: Killeen-Temple-Fort Hood, TX (EA) (57087)	1.063823
88: Knoxville-Sevierville-La Follette, TN (EA) (57088)	1.0552237
89: La Crosse, WI-MN (EA) (57089)	1.0434877
90: Lafayette-Acadiana, LA (EA) (57090)	1.0510775
91: Lake Charles-Jennings, LA (EA) (57091)	1.0510775
92: Las Vegas-Paradise-Pahrump, NV (EA) (57092)	1.0742184

93: Lewiston, ID-WA (EA) (57093)	1.0542885
94: Lexington-Fayette-Frankfort-Richmond, KY (EA) (57094)	1.047546
95: Lincoln, NE (EA) (57095)	1.0497406
96: Little Rock-North Little Rock-Pine Bluff, AR (EA) (57096)	1.0538686
97: Los Angeles-Long Beach-Riverside, CA (EA) (57097)	1.0502518
98: Louisville-Elizabethtown-Scottsburg, KY-IN (EA) (57098)	1.0453237
99: Lubbock-Levelland, TX (EA) (57099)	1.063823
100: Macon-Warner Robins-Fort Valley, GA (EA) (57100)	1.045969
101: Madison-Baraboo, WI (EA) (57101)	1.0435326
102: Marinette, WI-MI (EA) (57102)	1.0250034
103: Mason City, IA (EA) (57103)	1.0473558
104: McAllen-Edinburg-Pharr, TX (EA) (57104)	1.063823
105: Memphis, TN-MS-AR (EA) (57105)	1.0527586
106: Miami-Fort Lauderdale-Miami Beach, FL (EA) (57106)	1.0741463
107: Midland-Odessa, TX (EA) (57107)	1.0638173
108: Milwaukee-Racine-Waukesha, WI (EA) (57108)	1.0424635
109: Minneapolis-St. Paul-St. Cloud, MN-WI (EA) (57109)	1.0480733
110: Minot, ND (EA) (57110)	1.0658184
111: Missoula, MT (EA) (57111)	1.0695334
112: Mobile-Daphne-Fairhope, AL (EA) (57112)	1.0577604
113: Monroe-Bastrop, LA (EA) (57113)	1.0510775
114: Montgomery-Alexander City, AL (EA) (57114)	1.0577604
115: Myrtle Beach-Conway-Georgetown, SC (EA) (57115)	1.0461121
116: Nashville-Davidson-Murfreesboro-Columbia, TN (EA) (57116)	1.0534966
117: New Orleans-Metairie-Bogalusa, LA (EA) (57117)	1.0508591
118: New York-Newark-Bridgeport, NY-NJ-CT-PA (EA) (57118)	1.0441406
119: Oklahoma City-Shawnee, OK (EA) (57119)	1.061628
120: Omaha-Council Bluffs-Fremont, NE-IA (EA) (57120)	1.0484398
121: Orlando-The Villages, FL (EA) (57121)	1.0741463
122: Paducah, KY-IL (EA) (57122)	1.0452412
123: Panama City-Lynn Haven, FL (EA) (57123)	1.0741463
124: Pendleton-Hermiston, OR (EA) (57124)	1.0520388
125: Pensacola-Ferry Pass-Brent, FL (EA) (57125)	1.0741463
126: Peoria-Canton, IL (EA) (57126)	1.0407304
127: Philadelphia-Camden-Vineland, PA-NJ-DE-MD (EA) (57127)	1.0483679
128: Phoenix-Mesa-Scottsdale, AZ (EA) (57128)	1.0644274
129: Pittsburgh-New Castle, PA (EA) (57129)	1.0459251
130: Portland-Lewiston-South Portland, ME (EA) (57130)	1.0482784
131: Portland-Vancouver-Beaverton, OR-WA (EA) (57131)	1.0485279
132: Pueblo, CO (EA) (57132)	1.0491153
133: Raleigh-Durham-Cary, NC (EA) (57133)	1.0487924
134: Rapid City, SD (EA) (57134)	1.0572239
135: Redding, CA (EA) (57135)	1.0485122
136: Reno-Sparks, NV (EA) (57136)	1.0786543
137: Richmond, VA (EA) (57137)	1.0619457
138: Roanoke, VA (EA) (57138)	1.0612749
139: Rochester-Batavia-Seneca Falls, NY (EA) (57139)	1.0436035
140: Sacramento-Arden-Arcade-Truckee, CA-NV (EA) (57140)	1.0506136

141: Salina, KS (EA) (57141)	1.0498431
142: Salt Lake City-Ogden-Clearfield, UT (EA) (57142)	1.0612448
143: San Angelo, TX (EA) (57143)	1.063823
144: San Antonio, TX (EA) (57144)	1.063823
145: San Diego-Carlsbad-San Marcos, CA (EA) (57145)	1.0476305
146: San Jose-San Francisco-Oakland, CA (EA) (57146)	1.0478222
147: Santa Fe-Espanola, NM (EA) (57147)	1.063783
148: Sarasota-Bradenton-Venice, FL (EA) (57148)	1.0741463
149: Savannah-Hinesville-Fort Stewart, GA (EA) (57149)	1.0457698
150: Scotts Bluff, NE (EA) (57150)	1.053889
151: Scranton-Wilkes-Barre, PA (EA) (57151)	1.0465228
152: Seattle-Tacoma-Olympia, WA (EA) (57152)	1.0379954
153: Shreveport-Bossier City-Minden, LA (EA) (57153)	1.0510775
154: Sioux City-Vermillion, IA-NE-SD (EA) (57154)	1.0509777
155: Sioux Falls, SD (EA) (57155)	1.0590826
156: South Bend-Mishawaka, IN-MI (EA) (57156)	1.0366133
157: Spokane, WA (EA) (57157)	1.0502152
158: Springfield, IL (EA) (57158)	1.0388017
159: Springfield, MO (EA) (57159)	1.04344
160: St. Louis-St. Charles-Farmington, MO-IL (EA) (57160)	1.0395478
161: State College, PA (EA) (57161)	1.0465228
162: Syracuse-Auburn, NY (EA) (57162)	1.0428737
163: Tallahassee, FL (EA) (57163)	1.0611414
164: Tampa-St. Petersburg-Clearwater, FL (EA) (57164)	1.0741463
165: Texarkana, TX-Texarkana, AR (EA) (57165)	1.0562557
166: Toledo-Fremont, OH (EA) (57166)	1.0346975
167: Topeka, KS (EA) (57167)	1.0498431
168: Traverse City, MI (EA) (57168)	1.0223173
169: Tucson, AZ (EA) (57169)	1.0646691
170: Tulsa-Bartlesville, OK (EA) (57170)	1.062605
171: Tupelo, MS (EA) (57171)	1.0490262
172: Twin Falls, ID (EA) (57172)	1.0624351
173: Virginia Beach-Norfolk-Newport News, VA-NC (EA) (57173)	1.0560094
174: Washington-Baltimore-Northern Virginia, DC-MD-VA-WV (EA) (57174)	1.0607516
175: Waterloo-Cedar Falls, IA (EA) (57175)	1.0473558
176: Wausau-Merrill, WI (EA) (57176)	1.0399452
177: Wenatchee, WA (EA) (57177)	1.0379954
178: Wichita Falls, TX (EA) (57178)	1.063823
179: Wichita-Winfield, KS (EA) (57179)	1.0501543

APPENDIX E: NORTH CAROLINA COUNTY AVERAGE GROWTH FACTORS

County ID	Name	AGF
37001	Alamance County, NC	0.9815996
37003	Alexander County, NC	0.9890415
37005	Alleghany County, NC	0.9647669
37007	Anson County, NC	0.9956676
37009	Ashe County, NC	0.9987562
37011	Avery County, NC	0.9942681
37013	Beaufort County, NC	0.9855454
37015	Bertie County, NC	1.006422
37017	Bladen County, NC	1.0034279
37019	Brunswick County, NC	1.0320074
37021	Buncombe County, NC	1.0054405
37023	Burke County, NC	0.9804738
37025	Cabarrus County, NC	1.0142564
37027	Caldwell County, NC	0.9652762
37029	Camden County, NC	1.0468887
37031	Carteret County, NC	1.0108884
37033	Caswell County, NC	0.9610071
37035	Catawba County, NC	0.9690063
37037	Chatham County, NC	1.0059124
37039	Cherokee County, NC	0.9739654
37041	Chowan County, NC	1.0045574
37043	Clay County, NC	1.016526
37045	Cleveland County, NC	0.9784423
37047	Columbus County, NC	0.9908221
37049	Craven County, NC	1.0060371
37051	Cumberland County, NC	1.009876
37053	Currituck County, NC	1.0617362
37055	Dare County, NC	1.0311566
37057	Davidson County, NC	0.9761654
37059	Davie County, NC	0.9893712
37061	Duplin County, NC	0.9919422
37063	Durham County, NC	1.0029554
37065	Edgecombe County, NC	0.9860551
37067	Forsyth County, NC	0.9980497
37069	Franklin County, NC	1.0131183
37071	Gaston County, NC	0.9799729
37073	Gates County, NC	0.997766
37075	Graham County, NC	1.0057955
37077	Granville County, NC	1.0038896
37079	Greene County, NC	0.9826799
37081	Guilford County, NC	0.9947531
37083	Halifax County, NC	0.9853223
37085	Harnett County, NC	1.0061512
37087	Haywood County, NC	0.998304

37089	Henderson County, NC	1.0048213
37091	Hertford County, NC	0.9998456
37093	Hoke County, NC	1.0137758
37095	Hyde County, NC	1.0003652
37097	Iredell County, NC	1.0136959
37099	Jackson County, NC	1.0223795
37101	Johnston County, NC	1.0227836
37103	Jones County, NC	1.0097188
37105	Lee County, NC	0.9994014
37107	Lenoir County, NC	0.9919958
37109	Lincoln County, NC	1.0005795
37111	McDowell County, NC	1.0125699
37113	Macon County, NC	0.9971806
37115	Madison County, NC	1.0015016
37117	Martin County, NC	0.9866336
37119	Mecklenburg County, NC	1.0031399
37121	Mitchell County, NC	0.992907
37123	Montgomery County, NC	0.9786494
37125	Moore County, NC	0.996774
37127	Nash County, NC	0.9909878
37129	New Hanover County, NC	1.0196266
37131	Northampton County, NC	1.0463779
37133	Onslow County, NC	1.0042296
37135	Orange County, NC	1.0056545
37137	Pamlico County, NC	0.9900805
37139	Pasquotank County, NC	1.0224176
37141	Pender County, NC	1.0387546
37143	Perquimans County, NC	1.0384588
37145	Person County, NC	0.9797302
37147	Pitt County, NC	1.0023652
37149	Polk County, NC	1.0177212
37151	Randolph County, NC	0.9885038
37153	Richmond County, NC	0.9848109
37155	Robeson County, NC	0.9863726
37157	Rockingham County, NC	0.9831669
37159	Rowan County, NC	0.9965736
37161	Rutherford County, NC	0.9723739
37163	Sampson County, NC	1.0038873
37165	Scotland County, NC	0.9740334
37167	Stanly County, NC	0.9832925
37169	Stokes County, NC	0.9988026
37171	Surry County, NC	0.9726705
37173	Swain County, NC	1.0760252
37175	Transylvania County, NC	0.9668209
37177	Tyrrell County, NC	1.0259984
37179	Union County, NC	1.0234167
37181	Vance County, NC	0.9659083
37183	Wake County, NC	1.0114014

37185	Warren County, NC	0.9908167
37187	Washington County, NC	0.9981394
37189	Watauga County, NC	1.0041309
37191	Wayne County, NC	0.9911161
37193	Wilkes County, NC	0.9827447
37195	Wilson County, NC	0.9985829
37197	Yadkin County, NC	1.0011429
37199	Yancey County, NC	0.9592925

APPENDIX F: NORTH CAROLINA FAF2, SHORT-HAUL, AND TOTAL TRIP GENERATIONS

FAF2 is a synthesized nationwide database and it ignores some short haul truck trips; hence, we developed a method to incorporate these 'missing' short haul trips. The 'missing' trip productions and attractions are obtained using North Carolina employment data and adjusted quick response trip generation rates. Conceptually the manipulation is shown below and illustrated in Figure F.1.

FAF2 Trips $_{NC}$ = Long Haul (internal + external + I-E) Trips $_{NC}$
Short-haul Trip $_{NC}$ = NC Employment * quick response trip rate (internal + I-E)
Thus, Total Trips $_{NC}$ = FAF2 Trips $_{NC}$ + Short-haul Trips $_{NC}$

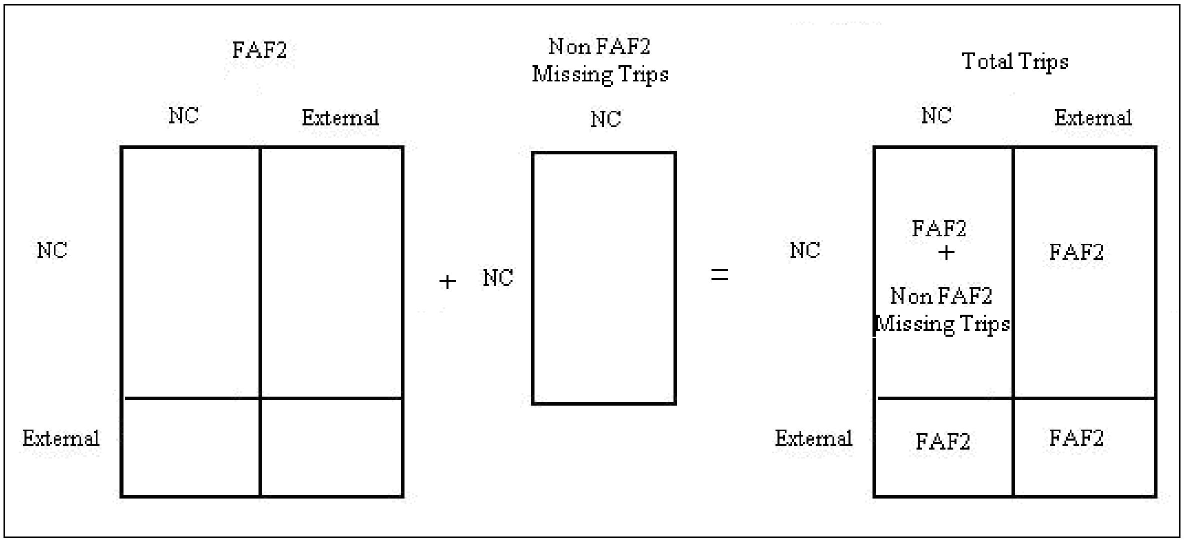

Figure F.1: Illustration of the Concept Involved in Estimating 'Missing' trips