FINAL REPORT

APPLICATION OF A STATEWIDE INTERMODAL FREIGHT PLANNING METHODOLOGY

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ABSTRACT

Anticipating the need for Virginia to comply with the new freight planning guidelines outlined by ISTEA and TEA-21, the Virginia Transportation Research Council in 1998 developed a Statewide Intermodal Freight Transportation Planning Methodology which provided a standard framework for identifying problems and evaluating alternative improvements to Virginia's freight transportation infrastructure. The first step in the methodology was to inventory the system. This study completed that step.

In this study, a freight advisory committee, consisting of public and private freight stakeholders, was formed. Next, county-level commodity flow data were commercially procured. Using these data, Virginia's "key" commodities were identified, and the flows of these commodities were assigned to county-level origin-destination (O-D) tables. A geographic information system (GIS) database, showing freight volumes, county-level population and employment information, and Virginia's freight transportation network, was developed. Using various statistical analysis techniques, freight generation and attraction relationships were defined, and predictive equations were developed for each of Virginia's key commodities. Future freight flows were predicted, and various models with which to distribute these future flows were evaluated.

The freight transportation GIS database, along with the analytical tools to predict and display future freight flows within Virginia, provides the Virginia Department of Transportation and its Freight Advisory Committee the means by which to identify problems, establish performance measures, and develop and evaluate alternatives to improve the flow of freight into, out of, and within Virginia.

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INTRODUCTION

Anticipating the need for Virginia to address the freight planning guidelines of ISTEA and TEA-21, the Virginia Transportation Research Council in 1998 developed a Statewide Intermodal Freight Transportation Planning Methodology, which provided a standard framework for identifying problems and evaluating alternative improvements to Virginia's freight transportation infrastructure.[1] The six steps of the freight planning methodology are as follows:

1. Inventory the system.
2. Identify the problem.
3. Establish performance measures.
4. Collect data and define conditions for specific problems.
5. Develop and evaluate improvement alternatives.
6. Select and implement improvements.

A technical transportation planning process is embedded in Step 1. This process has two components: the description of the existing freight transportation system and the forecast of specific commodities moving along the system in future years. The remaining steps of the Statewide Intermodal Freight Planning Methodology use the results of the system inventory to identify specific problems along the freight transportation network and develop improvement alternatives to address them. When fully implemented, this methodology can be used by the Virginia Department of Transportation's (VDOT) Transportation Planning Division (TPD) and the Virginia Department of Rail and Public Transportation (VDRPT) to identify and evaluate infrastructure improvements that may enhance the flow of freight into, out of, and through Virginia.

The “system inventory” is roughly analogous to the “definition of existing conditions” conducted in passenger transportation planning, which includes the definition of the existing passenger transportation infrastructure (including the highway and transit networks), the traffic volumes on that infrastructure, and the origins and destinations (O-Ds) of travelers. Similarly, the system inventory of the Statewide Intermodal Freight Transportation Planning Methodology involves the definition of the existing freight transportation infrastructure (including the highway, rail, water and air networks); the identification of the principal, or “key,” commodities moving along that infrastructure; and the acquisition of O-D data for those commodities. In addition, the system inventory involves forecasting future key commodity flows and developing a geographic information system (GIS) database on which to display current and future key commodity flows along the existing freight transportation network. Thus, the system inventory as discussed here is a much more robust procedure than the definition of existing conditions performed in traditional passenger transportation planning.

PURPOSE AND SCOPE

The purpose of this project was to implement the system inventory step of Virginia’s Statewide Intermodal Freight Transportation Planning Methodology. Implementing the system inventory will provide a foundation on which to continue applying the subsequent steps of the planning methodology, including identifying problems in Virginia’s freight transportation system, establishing performance measures with which to evaluate its performance, and developing and evaluating alternatives to improve the efficient flow of freight within Virginia.

Like most state departments of transportation, VDOT has little experience in freight transportation planning. To comply with the private sector participation requirements of ISTEA and TEA-21 and to take advantage of the freight transportation expertise in the private sector, the system inventory was conducted under the guidance of freight transportation stakeholders, including shippers, carriers, logistics providers, and other freight transportation interests from the public and private sectors.

METHODS

The implementation of the system inventory step was accomplished by performing the following tasks:

1. *Review existing literature.* The literature review focused on freight planning legislation, freight planning activities in other states, factors that affect the generation and attraction of freight, and the establishment and functions of freight advisory committees (FACs) in other states.

2. *Establish a Freight Advisory Committee (FAC).* Recommendations to VDOT were made regarding the establishment and operation of a Virginia FAC to assist in developing and implementing the freight planning process, and an initial meeting of the FAC was held.

3. *Collect data.* As freight movements are affected by many variables, several data sets were collected and analyzed during the course of this project. Transportation infrastructure data, including digital versions of Virginia's highway, rail, and water transportation networks, were collected for use in developing the freight transportation database. Commodity flow data, obtained from public and private sources, were used to define Virginia's key commodities and to display their flows on the freight transportation database. Socioeconomic data, such as employment and population statistics, were also acquired from public and private institutions. These data were used to formulate freight generation and attraction relationships, later used to predict future flows of freight throughout Virginia.

4. *Develop a freight transportation database.* A freight transportation database was developed and embedded in a GIS. This not only provides a format for graphically displaying base year and future commodity flows along Virginia's highway and rail networks, it can also be used to display the locations of existing and future intermodal freight facilities. Additionally, the database can be used as a freight planning tool, allowing easy access to important freight planning data, including county industry employment and population, for use by VDOT, VDRPT, and the FAC in evaluating the effects of infrastructure or demographic changes on Virginia's freight transportation system.

5. *Identify key commodities.* To minimize the number of commodities considered, only the key commodities deemed important to Virginia's transportation network and its economy were identified using the commodity flow data collected.

6. *Develop freight generation methods, and complete the technical freight transportation planning process***.** Freight generation methods were developed by using statistical analysis techniques to define relationships among commodity generation, or origins of freight traffic; attraction, or destinations of freight traffic; and publicly available socioeconomic data. These relationships were then used to predict the generations and attractions of each key commodity in each Virginia county and independent city. Ways in which to adapt the remaining steps of the traditional (i.e., passenger) transportation planning process (i.e., distribution, mode choice, and traffic assignment) to freight movements were investigated and evaluated.

RESULTS

Literature Review

A literature search was performed in the previous phase of this project;[1] the search focused on federal requirements and regulations for statewide freight planning, the general freight planning process, public and private involvement in the freight planning process, data requirements, and freight planning efforts in other states and metropolitan areas. The literature search in this phase of the study, which builds upon the earlier literature review, focused on freight planning legislation, freight planning efforts in other states (particularly those states applying predictive freight models), the development of freight generation and attraction factors, and the establishment of FACs in other states.

Federal Freight Planning Legislation

Statewide freight planning was introduced with the passage of ISTEA in 1991, in which the federal government encouraged states to "undertake a continuing, cooperative, and comprehensive transportation planning process" taking into consideration 23 planning factors. Two of these factors dealt explicitly with the transport of freight, "international border crossings and access to ports, airports, intermodal transportation facilities [and] major freight distribution routes [as well as] methods to enhance the efficient movement of commercial vehicles." In addition, ISTEA mandated public involvement in the transportation planning process, requiring that states "provide citizens, affected public agencies, representatives of transportation agency employees, other affected employee representatives, private providers of transportation, and other interested parties with a reasonable opportunity to comment on proposed [transportation improvement] plan[s]."

ISTEA was reauthorized as TEA-21 in 1998. Although TEA-21 continued ISTEA's emphasis on the statewide transportation planning process and public involvement in these processes, it consolidated ISTEA's 23 transportation planning factors into seven broader planning areas to be considered during the planning process. Three areas related to freight transport, specifically to "support the economic vitality of the United States, the States, and metropolitan areas, especially by enabling global competitiveness, productivity, and efficiency . . . to increase the accessibility and mobility options available to people and for freight . . . [and] to enhance the integration and connectivity of the transportation system, across and between modes throughout the State, for people and freight." TEA-21 further strengthened ISTEA's public involvement mandate by identifying "freight shippers [and] providers of freight transportation services" as participants in the transportation planning process.

Freight Planning in Other States

Even after the passage of ISTEA, very few states were considering the impact of freight movements in their overall transportation systems. As of 1993, only seven states were attempting to use freight forecasts in the transportation planning process.[2] They were not doing so on an intermodal level, rather they were merely "dealing with the requirements of the State

Rail Plan [required by the Federal Railroad Administration] or with rail line abandonments."[2] States are now becoming more comfortable with their intermodal planning roles defined by ISTEA and TEA-21, however, and many have begun to realize the importance of freight transportation to their overall economic vitality.[2] Several have even begun to work in the public and private sectors to identify and address freight transportation concerns, including Florida, California, Oregon, New Jersey, and Massachusetts, among others. Few states, however, have taken an active role in attempting to model the demand for freight transportation and use those models to predict future freight flows and identify beneficial infrastructure or policy improvements. Among those states that have attempted to create freight planning models are Iowa, Minnesota, and Wisconsin.

Iowa

Researchers at Iowa State University's Center for Transportation Research and Education developed a "layered" approach to transportation demand modeling in 1998 in which a statewide freight transportation demand model was constructed one commodity at a time.[3] The researchers believed that as most regional economies are dominated by only a few economic sectors, freight traffic growth could be accurately modeled by estimating the growth or decline of these industries. The effectiveness of this technique was demonstrated through the modeling of trucked freight traffic (at a county level) for the commodities deemed most important to Iowa's economy: the meat production and farm machinery industries. Other commodities were to be added later to develop a more complete model of Iowa's freight transportation system. O-D data for these two commodities were estimated using the Iowa Truck Weight Survey although the TRANSEARCH database (Reebie Associates, Stamford, Connecticut) will be used in future analyses.

The production levels of meat processing and farm machinery were estimated using industry employment data obtained from the Iowa Department of Workforce Development. The level of attraction for the meat processing industry was based on county population (available from the U.S. Census), and attraction factors for the farm machinery industry were based on acreage of farmland (available from the U.S. Census of Agriculture). The researchers hope to add commodity layers to develop a more complete model of Iowa's freight transportation demand.[3] This demand model can then be used to predict future freight flows and prioritize freight infrastructure improvements.

Minnesota

Minnesota completed a regional freight flow study in 1998[4] to identify the value of commodities flowing along major corridors and relate them to the economic importance of the transportation links. This information was to be used by transportation planners in evaluating infrastructure improvements to the transportation system. The study was limited to 12 counties in the northwest corner of the state, included only truck and rail flows, and considered only base year commodity flows.

Commodity flow information was obtained from the 1993 Commodity Flow Survey (CFS) for Minnesota and the TRANSEARCH database. A "layered" approach was used, focusing on sugar beets, grain, timber, and "manufactured commodities." Industry employment and the economic structure of the 12-county region were evaluated using the IMPLAN (Minnesota IMPLAN Group, Inc., Stillwater, Minnesota) input-output model. Although only base year commodity flow data were used to identify significant freight corridors, Minnesota could use the commodity flow information combined with the IMPLAN economic model to predict freight flows and evaluate the need for transportation infrastructure improvements along those corridors.

Wisconsin

The Wisconsin Department of Transportation completed a comprehensive freight planning study[5] as part of Wisconsin's long-range transportation plan, *Translinks 21*, in 1996. In contrast to the Iowa study, the Wisconsin project was multimodal in scope: TRANSEARCH county-level commodity flow data were obtained for the truck, rail, water, and air modes. These base year commodity flow data were forecast to 2020 by estimating changes in industrial employment and productivity using the following logic:

- Changes in employment modified by changes in productivity yield changes in output.
- Output dictates freight shipments.
- Commodities can be related to shipping industry output through Standard Industry Classification (SIC) codes.[5]

Employment was forecast for 92 industry classes (based on two-digit SIC codes), and productivity changes were forecast by estimating the change in output per employee for each industry over the time period. To create freight forecasts, base year commodity flow data were "adjusted using the combined rate of change for employment and productivity specific to that origin and the relevant industry."[5] These predicted commodity flows were assigned to Wisconsin's highway and rail networks, as well as water and air ports. A freight expert panel was established to review the forecasts and estimate the effects on Wisconsin's freight transportation system.

Sorratini later used 1993 CFS, the TRANSEARCH database, and an economic input-output model to generate truck flows disaggregated to the Traffic Analysis Zone level for Wisconsin.[6] Freight production rates were estimated using U.S. Bureau of Transportation statistics (http://www.bts.gov/programs/cfs/sctg/welcome.htm) and U.S. census data. Freight attractions were estimated using an economic input-output model created by IMPLAN. The model was used to calculate input-output coefficients that were then used to develop freight attraction rates.

Freight Generation Factors

As "the derived demand [for freight transportation] is closely related to some index of real output,"[7] measures of industry output are normally used to estimate current and future commodity production levels. According to the U.S. Department of Transportation's *Quick Response Freight Manual*,[8] the most desirable measures are those that quantify goods output in physical units. However, as forecasts of these variables are not generally available, dollar measures of output, employment, population, or real personal income are normally used as indicator variables.

The Southern California Association of Governments[9] employed a similar method. Their model assumes that commodity flows (for manufacturing SIC codes 1-8 and 20-39) are directly proportional to employment levels and allocates commodities to counties "based on the employment share in the producing SIC industry."[9] The generation of mining products (SIC codes 10-14), however, was related to land use, whereas the generation of coal in an area, for instance, was linked to the total amount of coal mine acreage in the area.

In Iowa's freight planning typology,[3] two commodities were considered: meat products and farm machinery. As discussed earlier, the generation of both commodities was estimated by determining the levels of employment in the two industries.

Freight Attraction Factors

Although freight generation factors can be estimated using industry employment and/or output data, the development of freight attraction factors is more complicated, as individual commodities are often attracted not only by individual consumers, but also by industries involved in secondary manufacturing processes. Kanafani[10] described three approaches useful for developing freight attraction factors: the microeconomic or microscopic approach, spatial interaction modeling, and the macroeconomic approach.

The microscopic approach considers freight attraction at the individual firm level. In a microscopic analysis, "the demand for commodity transportation is derived by considering transportation as one of the inputs into the production of the firm;"[10] that is, if commodity generation involves transportation of goods or services, the firm is a consumer of transportation. The degree to which transportation services are consumed can then be considered the attraction factor for the firm. Although microscopic models can be useful in determining attraction factors for individual firms or commodities, they become cumbersome when they are used in a multi-region, multi-commodity analysis. As Norton[11] stated, "there are hundreds of price-place relationships which will determine the economics of transporting any given commodity from or to any given production center." As these relationships are dynamic, determining how an attraction factor will change over time is very difficult.

Spatial interaction modeling involves surpluses and deficits of commodities at various points in an analysis zone. Commodities are then said to flow from surplus areas to deficit areas.[10] Again, although this process can be useful in determining attraction factors for individual commodities, it can become cumbersome when used in a multi-region, multi-commodity analysis.

The macroeconomic analysis of transportation demand deals with inter-industry flows of goods and services. This is accomplished in one of two ways. The first is the econometric approach in which “systems of simultaneous equations are used to relate the intersectoral requirements and flows.”[10] This type of analysis can be complicated and time-consuming. The second is to use input-output models. To produce its output, a given production sector of a regional economy requires inputs from other sectors in the region. Input-output models attempt to quantify these inter-industry relationships and show how the output of individual production sectors will change in response to changes in final demand.

Simpler methods have also been used to estimate freight attraction. In Iowa’s freight planning typology,[3] for instance, the attraction of farm machinery was assumed to be proportional to acres of farmland. Population was also used to estimate the amount of freight attracted to a particular area.

Freight Advisory Committees

Private sector involvement is critical in addressing statewide freight planning issues. The concept of private sector involvement in the freight planning process was introduced in ISTEA and strengthened by TEA-21. Private sector involvement in freight planning is effectively provided by a FAC. Several states have established FACs, including Washington, California, Florida, Oregon, Massachusetts, Louisiana, and Maryland.[12] A study of the FACs established by these states published earlier provides excellent background information with which to establish a FAC in Virginia.[12]

Virginia’s Freight Advisory Committee

As freight transportation is essentially a private sector enterprise, private sector involvement is critical when addressing statewide freight planning issues. Based on the review of other states’ freight planning initiatives,[12] the following section represents a proposed mission, goals, and membership of Virginia’s FAC. These recommendations were provided to VDOT’s TPD, which organized the inaugural meeting of Virginia’s FAC.

Proposed Mission

The proposed mission of Virginia’s FAC is to provide a public/private forum in which to enhance the effective movement of freight throughout Virginia, which is crucial to the economic health of Virginia. The group shall act as an advocate for the freight community and advise policymakers on issues that emphasize the reliable, intermodal, efficient, safe, and environmentally responsible movement of freight.

Proposed Goals

The proposed goals of Virginia's FAC are as follows:

- Educate planners, engineers, and policy makers about the significance of freight movement and how it affects Virginia's economic viability.
- Advise VDOT and VDRPT about freight movement trends and future issues that may affect the effective flow of goods in Virginia.
- Participate in the development of Virginia's Statewide Transportation Plan.
- Investigate and promote, as appropriate, new technologies and alternative strategies to improve the effective movement of goods.
- Serve as an advocate for policies and legislation that improve freight mobility.
- Establish and maintain effective communication between the freight community and VDOT and VDRPT.

FAC Status

VDOT's TPD organized Virginia's FAC in August 2000. The inaugural meeting was held on September 25, 2000, in Charlottesville with representatives from the following organizations in attendance:

- VDOT
- VDRPT
- Virginia Transportation Research Council
- Virginia Port Authority
- Virginia Economic Development Partnership
- Norfolk Southern Railroad
- Virginia Rail Association
- Wyatt Transfer, Inc. (private drayage company)
- Virginia Trucking Association

- Federal Aviation Administration.

The group received briefings on current statewide freight planning initiatives, including the Virginia Statewide Transportation Plan. At the conclusion of the meeting, the group agreed to meet periodically to discuss statewide freight planning issues and their role in the process.

Data Collection

Several data types from public and private sources were collected and analyzed during the course of this project, including transportation infrastructure data, commodity flow data, and socioeconomic data.

Transportation Infrastructure Data

Virginia's transportation infrastructure consists of several major roadways (including federal and state highway systems), a highly developed rail network, a small inland waterway system, and several cargo airports.

Virginia's Highway Network

Virginia is home to more than 66,000 miles of roadway,[13] of which 3,561 miles are designated as part of the National Highway System,[14] a nationwide system of roadways designated by the Federal Highway Administration. The system consists of "the interstate highway system, other routes designated as 'strategic highway network corridors,' network connectors for military installations, and congressional high priority corridors."[1]

Oak Ridge National Laboratory's Center for Transportation Analysis (CTA) maintains a digital link-node version of the U.S. highway transportation network designed to facilitate traffic routing and analysis. This network is publicly available from the CTA website and was downloaded in an ArcView GIS format. A complete description of the sources, attributes, and accuracy of the CTA highway network is available on the CTA website (http://www-cta.ornl.gov/transnet/nhndescr.html). The downloaded ArcView file consists of the highway network for the entire United States. Using data manipulation commands within ArcView, it was possible to display only the Virginia portion of the network.

Virginia's Rail Network

Virginia is home to nine freight railroads operating on 3,270 miles of track.[15] Among these railroads are two Class I railroads, CSX and Norfolk Southern (together accounting for more than 92% of the total truck mileage in Virginia); five local railroads; and two switching and terminal railroads.[15] In Virginia, CSX operates large freight yards in Alexandria, Clifton Forge, Newport News, Norfolk, Portsmouth, and Richmond. In addition, CSX has an intermodal transfer terminal in Portsmouth and rail-to-truck transloading facilities in Newport News and Richmond. On the periphery of Virginia, CSX has a major presence in Baltimore, where it operates a rail-to-truck transfer facility and an intermodal terminal. CSX also owns rail-to-truck transfer facilities in Charleston, West Virginia, and Charlotte, North Carolina, and an intermodal terminal in Charlotte.

Norfolk Southern operates two freight facilities in Virginia, one in Roanoke and one in Manassas. Like CSX, Norfolk Southern has a major presence in Baltimore, where it operates an intermodal facility, and owns freight facilities in Charlotte, North Carolina; Hagerstown, Maryland; and several locations in Pennsylvania.

CTA also maintains a digital link-node version of the U.S. rail transportation network designed to facilitate traffic routing and analysis. The network is publicly available from the CTA website and was downloaded in an ArcView GIS format. A description of the sources, attributes, and accuracy of the CTA rail network is available on the CTA website (http://www-cta.ornl.gov/transnet/rrdescr.txt). Like the highway network file, the downloaded rail file consists of the entire U.S. rail network, and data manipulation commands were used to display only the Virginia portion of the network.

Virginia's Waterway Network

Virginia's waterway system consists of a large international container port at the meeting of the James River and the Chesapeake Bay and a smaller inland waterway system located along the many rivers and creeks throughout Virginia.

The Port of Virginia consists of four terminals: the Newport News Marine Terminal, the Norfolk International Terminal, the Portsmouth Marine Terminal, and the Virginia Inland Port. The Newport News and Portsmouth terminals handle mainly breakbulk and roll-on/roll-off cargo. The Norfolk terminal handles mainly containerized cargo and is one of the largest container ports on the East Coast. The Virginia Inland Port is a truck/rail intermodal facility located in Front Royal.

Digital link-node versions of the U.S. inland waterway system are maintained by the U.S. Army Corps of Engineers and are publicly available from their Navigation Data Center. As was done with the CTA highway and rail files, the inland waterway network was manipulated within ArcView to display only the Virginia portion of the U.S. inland waterway system.

Virginia's Air Transportation System

The locations and characteristics of Virginia's cargo airports were collected from the Virginia Department of Aviation. Though airport information was not supplied as an ArcView GIS coverage, location and characteristic information was manually entered into and displayed on an existing GIS coverage.

Commodity Flow Data

The availability of detailed, accurate commodity flow data is often a problem for states in conducting freight planning. As the freight transportation industry is highly competitive, private freight transportation companies are reluctant to provide commodity flow data, fearing that rival companies may use it to improve their competitive advantage. The data that are available publicly, on the other hand, are often not published at an appropriate level of detail to conduct statewide freight planning. The following sections provide a more detailed discussion of the important types of commodity flow data available and the data used in this study.

U.S. Bureau of Transportation Statistics Commodity Flow Survey

The CFS, a joint effort among the U.S. Census Bureau, the U.S. Department of Commerce, and the U.S. Department of Transportation's Bureau of Transportation Statistics, is conducted every 4 years to provide goods movement information at the state level. The CFS provides flows of commodities originating in Virginia on six modes: truck, rail, water, air, pipeline, and "multiple modes." Commodities are identified using Standard Classification of Transported Good (SCTG) system, which is based on the Harmonized System of product classification. A list of these codes is provided in Appendix A. The sample size for the 1997 CFS is approximately 5 million shipments.[16]

Although these data are widely used in other types of studies, the CFS has inherent weaknesses that make it inappropriate for use in this study. First, CFS data are available only at the state level; county-level data are more appropriate for use in a statewide freight planning process. If CFS data were to be used in this study, a methodology to disaggregate the statewide commodity flows to individual counties and cities would have to be developed. Such a disaggregation process, most likely based on county-level employment and population, would likely affect the accuracy of the final (county-level) commodity flow data.

Second, the CFS only considers shipments of freight that originate in an individual state. CFS data for Virginia, for instance, only includes information for commodities originating in Virginia. Commodities being imported to the state (external-internal flows) and commodities simply moving through the state (through flows) are not accounted for in the CFS data. As Virginia is home to a major deep-water port, one east-west interstate highway (I-64), and four north-south interstate highways (I-77, I-81, I-85, and I-95), external-internal and through movements must be taken into consideration to gain an accurate picture of the freight movements in Virginia.

Third, the CFS it includes only shipments from business establishments in mining, manufacturing, wholesale trade, and selected retail industries.[16] Farm, forest, fishery, construction establishments, and parcel and U.S. Postal Service shipments are not included. Such exclusions limit the accuracy of the CFS, particularly in rural states such as Virginia, which have high numbers of farm, forest, and fishery industries.

Fourth, as it is published by the U.S. Census Bureau, the CFS must conform to federal law governing census reports, including the prohibition of publishing data that would disclose the operations of an individual firm or establishment. As a result, much of the data are not published, severely reducing the accuracy and scope of the CFS.

TRANSEARCH Database

Through agreements with private carriers across all modes, Reebie Associates compiles detailed commodity flow movements at a county level with a higher degree of accuracy than the CFS. The TRANSEARCH database provides flows of commodities originating, terminating, or moving through Virginia on five modes: truck, rail carload, water, air, and rail intermodal. The commodities are identified using the Standard Transportation Commodity Codes (STCC) published by the American Association of Railroads. A list of these codes is provided in Appendix B. The sample size for the 1998 TRANSEARCH database is approximately 50 million shipments. The database is compiled using publicly available data, such as railroad waybill samples and trade statistics, and proprietary shipment information, including the Annual Motor Carrier Data Exchange. This combination of data sources leads to a more detailed commodity flow database.

A weakness of the TRANSEARCH database is that “special” generators of freight, such as deep-water ports, are not individually identified. Tonnage originating and terminating at these special generators is included with the total amounts calculated for the surrounding city or county. Commodity tonnage originating or terminating at the Port of Virginia, for example, is assigned to Newport News, Norfolk, or Portsmouth. This limitation can lead to abnormally high amounts of freight originating or terminating in these areas and may affect attempts to develop freight generation and attraction relationships.

Virginia Port Authority Import/Export Statistics

The Virginia Port Authority publishes a list of the top 20 imports and exports through the Port of Virginia by weight and value. Although these imports and exports are not identified by STCC, they are identified by product name. This product name can then be converted into a STCC or SCTG code. Although these data are not useful in the analysis of total commodity movements throughout Virginia, they can be used to verify commodity flow data obtained from other sources.

Final Makeup of Commodity Flow Data

As it provides the most extensive and detailed commodity flow data, the TRANSEARCH database (1998) was the primary source of commodity flow data used in the completion of this project. However, the 1997 CFS and the Port of Virginia Import and Export Statistics were consulted to verify the accuracy of the final list of Virginia’s key commodities and to ensure that each important commodity was included. The TRANSEARCH database procured for this project provided the following information on commodity flows into, out of, and within Virginia:

- county-to-county commodity flows at the four-digit STCC level for geography in Virginia and from points on the periphery of Virginia;

- state-level commodity flows at the four-digit STCC level for surrounding states;

- BEA-level commodity flows at the four-digit STCC level for the following metropolitan areas: New York; Philadelphia; Salisbury, Maryland; Winston-Salem, North Carolina; Raleigh-Durham, North Carolina; Charlotte; Miami; Atlanta; Johnson City, Tennessee; Lexington, Kentucky; Charleston, West Virginia; Pittsburgh; Chicago; and Houston;

- census region level commodity flows at the four-digit STCC level for distant regions; and

- commodity flow data by annual volume and value for each of the following modes of transport: truckload, less-than-truckload (LTL), private truck, rail carload, rail intermodal, water, and air.

Files showing commodity volumes routed along Virginia's highway and rail networks were also provided. These files were compatible with the highway and rail network files obtained from CTA and were exported into an ArcView GIS format for display on the freight transportation GIS database.

Socioeconomic Data

Like passenger movements, which can be related to such variables as persons per household, car ownership, and income, freight movements are affected by socioeconomic variables. Many socioeconomic variables, including population, employment, and per capita income, were collected to define freight generation and attraction relationships.

Population Data

Population data are often used to predict freight attraction in an area. Population data for each of Virginia's 136 counties and independent cities were acquired from the U.S. Census Bureau. To match these data with the 1998 TRANSEARCH commodity flow data, 1998 Census Bureau population estimates (based on the 1990 census) were used.

Employment Data

Employment data are often used to predict freight production in an area. County-level employment data are available from the U.S. Census Bureau through their County Business Patterns Series. County Business Patterns is published annually and provides county-level employment data based on SICs. Like the CFS, however, County Business Patterns must conform to federal law governing census reports, including the prohibition of publishing data that would disclose the operations of an individual firm or establishment. As a result, much of the employment data are not published, severely reducing the accuracy and scope of this dataset.

More complete county-level employment data were procured from the Minnesota IMPLAN Group, Inc., which develops and maintains the IMPLAN database. Originally designed to create regional input-output models for use in estimating economic and social impacts of industry or employment changes, IMPLAN also provides complete base year industry employment data in 528 employment sectors, which consist of one or more four-digit SICs. With little manipulation, these 528 employment sectors can be aggregated into two-digit SIC groupings, which are equivalent to STCC groups at the two-digit level of detail. Though only the employment data feature of the IMPLAN database was used in this phase of the project, its input-output features may be useful in future freight planning efforts.

Other Data

Population and employment are not the only variables that may affect freight generation and attraction. County and independent city size, in square miles, was provided by the Weldon-Cooper Center for Public Service at the University of Virginia. Population density, in population per square mile, was then calculated using the population data previously collected. The Weldon-Cooper Center also provided county-level per capita income data, which may affect freight attraction at the county-level.

As coal is often used in power generation, the locations of fossil-burning power generation plants in Virginia were identified from Dominion Virginia Power. Other data collected from this source included plant daily coal consumption, plant kilowatt capacity, and daily coal consumption per kilowatt. These socioeconomic data were compiled into a spreadsheet for use in the development of freight generation and attraction relationships.

Freight Transportation GIS Database

The desired characteristics of a GIS freight transportation database for Virginia were identified in 1996,[17] and a database was constructed using the Environmental Systems Research Institute's (ESRI) Arc/Info, a UNIX-based GIS application.[18] The characteristics of this database were used as the starting point for the GIS freight transportation database created in this project, though ESRI's Arc/Info was not used. Since 1996, several advances have been made in the usefulness of other GIS applications and the availability of state and nationwide transportation networks designed specifically for use in those applications. The freight transportation database created in this project was developed using ESRI's ArcView 3.2, a more user-friendly, Windows-based GIS application.

The following sections describe the desired characteristics of Virginia's GIS freight transportation database originally identified in 1996 and the final characteristics of the database developed in this project. In addition, examples of the coverages included in this database are provided, a methodology to display commodity flows on these coverages is presented, and the anticipated uses of the final freight transportation GIS database are discussed.

Desired Characteristics of a Freight Transportation GIS Database

Goodloe et al. identified the desired general characteristics of a GIS freight transportation database in 1996[17] and assigned them to one of three categories: facilities and connections, constraints, and flows. These characteristics are listed in Table 1.

Table 1. Original Desired Characteristics of the Freight Transportation GIS Database

Facilities and Connections	Constraints	Flows
Highway network Truck terminals Railway network Intermodal terminals Waterway network Ports Airport network Airports Distribution centers Manufacturers	Height restrictions Weight restrictions Crossings (grade, bridge, etc.) Time of operation restrictions Capacity Travel times Channel depths	Traffic volumes Vehicle classification Commodity flows Origins/destinations

Source: Goodloe et al., *Development of a GIS Freight Transportation Database*, Report UVA/29242/CE97/102, Mid-Atlantic Universities Transportation Center, University Park, Pa., 1996.

Final Characteristics of Virginia's Freight Transportation GIS Database

The researchers made the following additions and deletions to the GIS freight transportation database developed in this project.

Additions

- county- and independent city-level population from the U.S. Census;
- SIC-level employment data from 82 industries (derived from IMPLAN); and
- annual employment growth rates for each industry using estimates from the Virginia Employment Commission.

Exclusions

- *Truck terminals and manufacturers.* Plotting the locations of every truck terminal and manufacturer within Virginia is a daunting task. Since freight O-Ds were defined only at the county/independent city level, identifying the locations of these terminals and manufacturers was unnecessary. Future researchers may wish to include this information to refine and improve the database.

- *Intermodal distribution centers other than Norfolk Southern and CSX intermodal distribution centers.* Identifying every distribution center in Virginia is a cumbersome task. Future researchers may wish to include this information to create a more complete database.

- *Precise restrictions, including height, weight, and time of operation restrictions.* These characteristics were not provided in the CTA's digital highway and rail network files; however, highway links that are closed to large trucks are identified.

- *Crossings.* Future researchers may wish to add this information, as crossings may contribute to bottlenecks along the transportation network.

- *Traffic volumes and vehicle classifications.* Commodity flows were provided and displayed in tons. Future researchers may wish to convert these tons to individual vehicles traveling on the network.

The characteristics included in Virginia's GIS freight transportation database are provided in Table 2.

Table 2. Final Characteristics of Virginia's Freight Transportation GIS Database

Facilities	Constraints	Flows	Other Information
Highway network Rail network Waterway network Marine ports Airports Norfolk Southern/CSX intermodal facilities	Highway truck restrictions Travel times	Origins/destinations Commodity flows	Population (and growth rate) Industry employment levels (and growth rate)

Coverages Included in the Freight Transportation GIS Database

A GIS coverage is simply a data file in which geographic features are stored as points, lines, and polygons, and attributes assigned to these features are stored in tables.[18] Table 3 provides a list of coverages used in Virginia's freight transportation GIS database.

Two of the most useful coverages included are the key commodity flow coverages, which provide graphical representations of commodity flows along the Virginia highway and rail networks. These coverages can be helpful to VDOT and the FAC in identifying freight transportation problems along these networks. Figure 1 provides a sample of a key commodity flow coverage for STCC 3700 (transportation equipment) commodities traveling by truck.

Table 3. Coverages Included in Virginia's Freight Transportation GIS Database

Coverage	Attributes	Source
Virginia counties/independent cities	Population, employment, annual employment growth	University of Virginia Geospatial & Statistical Data Center
Principal BEAs	Population	University of Virginia Geospatial & Statistical Data Center
Principal states	Population	University of Virginia Geospatial & Statistical Data Center
Census divisions	Population	University of Virginia Geospatial & Statistical Data Center
Virginia interstate highway network	Length, number of lanes, functional class, access control, restrictions	Oak Ridge National Laboratory Center for Transportation Analysis[19]
Virginia U.S. routes	Length, number of lanes, functional class, access control, restrictions	Oak Ridge National Laboratory Center for Transportation Analysis[19]
Virginia railroad network	Length, owner/operator	Oak Ridge National Laboratory Center for Transportation Analysis[19]
Virginia waterway network	Length, heading, waterway type, channel depth	U.S. Army Corps of Engineers[20]
Virginia airports	Location	Virginia Dept of Aviation[21]
Norfolk Southern and CSX Terminals	Location, type	Norfolk Southern[22] CSX[23]
Key commodity flows (truck)	Volume (in tons) on each highway network link (see Figure 1)	N/A
Key commodity flows (rail)	Volume (in tons) on each rail network link	N/A

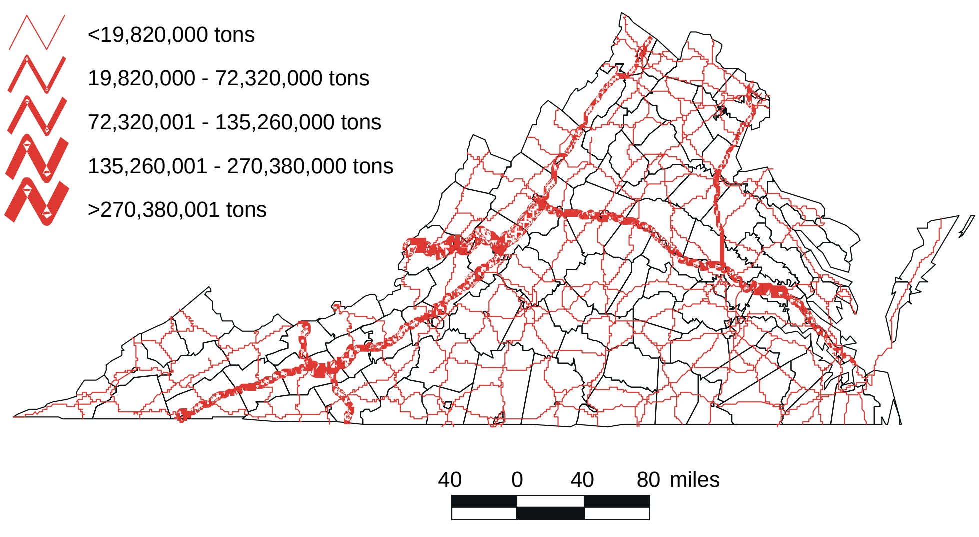

Figure 1. Total STCC 3700 Tonnage by Truck

Identification of Key Commodities

The following sections describe the methodology used to identify Virginia's key commodities using the TRANSEARCH database, the list of Virginia's key commodities, and the impact of those commodities on Virginia's total and manufacturing gross state product (GSP).

Methodology

The TRANSEARCH database used in this study consisted of commodity flows (by ton) into, out of, and through Virginia and is presented in two subsets: one showing freight movements originating and/or terminating in Virginia, and the other showing freight movements through Virginia. Flows were on a county-to-county-level, and commodities were classified at the four-digit STCC-level and assigned to one of five modes: truck, rail, water, air, and intermodal. Although originating and terminating movements were assigned to each of these modes, through movements were provided only for the truck, rail, and intermodal modes. So that commodities could be analyzed by weight and value, a 1998 ton-to-dollar conversion table was also provided.

Different modes have different service characteristics, and the commodities carried by those modes also differ. The truck and air modes tend to be dominated by low-weight, high-value commodities, such as automobile and computer parts. Conversely, the rail and water modes tend to be dominated by high-weight, low-value commodities, including coal, gravel, and timber. To understand the entire picture of freight movements across Virginia and to ensure that the key commodities were not slanted toward one particular mode, commodity flows were analyzed by both weight and value.

Virginia's Key Commodities

Virginia's key commodities are composed of the most prevalent commodities among the five modes (by weight or value). The final list of commodities, showing the total weight (originating + terminating + through), value (originating + terminating + through), and modal and overall percentages are provided in Tables 4 through 6. As can be seen, Virginia's key commodities account for more than 68 percent of the total weight and almost 52 percent of the total value shipped within the state.

Although the key commodities provide an accurate representation of the freight moving throughout Virginia, some commodities, such as mail and express traffic (STCC 4300), scrap (STCC 4000), and mixed freight shipments (STCC 4600), were not included even though they might comprise a significant portion of the total shipments for a particular mode. Mail and express traffic (STCC 4300), for instance, accounted for 54.6 percent of the weight and 97.2 percent of the value of all air shipments. Although such commodities also accounted for a large portion of the total weight and value shipped within Virginia, they were not included in the final list because, unlike most of the key commodities, they were not considered manufactured goods.

Table 4. Virginia's Key Commodities

STCC	Commodity
3700	Transportation Equipment
2800	Chemicals or Allied Products
3600	Electrical Machinery, Equipment, or Supplies
3500	Machinery, excluding Electrical
2000	Food and Kindred Products
2600	Pulp, Paper, or Allied Products
3000	Rubber or Miscellaneous Plastics Products
3200	Clay, Concrete, Glass or Stone Products
2400	Lumber or Wood Products, excluding Furniture
1100	Coal
1400	Non-metallic Ores and Minerals, excluding Fuels
2300	Apparel or Other Finished Textile Products or Knits
2100	Tobacco Products, excluding Insecticides
2700	Printed Matter
2900	Petroleum or Coal Products

Table 5. Tonnage Breakdown of Key Commodities

STCC	Total Tonnage	% of Truck Tonnage	% of Rail Tonnage	% of Water Tonnage	% of Air Tonnage	% of Intermodal Tonnage	% of Total Tonnage (All Modes)
3700	13,271,441	3.55	0	1.16	5.51	2.14	2.27
2800	67,276,462	9.55	5.20	2.02	3.12	3.41	7.72
3600	20,919	0	0	0	5.72	0	0.01
3500	432,840	0	0	1.07	10.02	0	0.05
2000	59,985,337	9.85	2.33	0	0	3.78	6.89
2600	38,011,198	5.39	3.06	0	0	3.00	4.36
3000	12,544,019	2.34	0	0	0	0	1.44
3200	73,930,685	12.38	2.62	0	0	0	8.49
2400	64,721,813	11.11	1.74	0	0	0.95	7.43
1100	196,842,645	0	69.41	0	0	0	22.60
1400	25,474,001	0	5.80	24.38	0	0	2.92
2300	250,934	0	0	0.68	0	0	0.03
2100	*	*	*	*	*	*	*
2700	12,384	0	0	0	3.39	0	0.01
2900	38,883,674	5.62	0.54	19.39	0	0	4.46
Total	591,658,352	59.79	90.70	48.70	27.76	13.28	68.68

*Low-weight, high-value commodity providing negligible contribution to overall tonnage.

Table 6. Value Breakdown of Key Commodities

STCC	Total Value ($)	% of Truck Value	% of Rail Value	% of Water Value	% of Air Value	% of Intermodal Value	% of Total Value (All Modes)
3700	123,390,790,136	12.45	27.54	1.89	0.45	0.55	9.66
2800	100,807,751,328	11.03	16.76	0	0.06	0.10	7.88
3600	88,039,244,751	10.83	0	0	0.51	0	6.90
3500	91,693,185,710	10.57	1.80	3.09	0.81	0.42	7.24
2000	54,576,670,964	6.66	4.41	0	0	0.41	4.52
2600	52,135,790,109	5.71	8.76	0	0	0	4.09
3000	43,809,821,417	5.42	0	0	0	0	3.43
3200	*	*	*	*	*	*	*
2400	14,311,659,972	1.60	1.99	0	0	0	1.12
1100	5,164,512,478	0	7.58	0	0	0	0.40
1400	*	*	*	*	*	*	*
2300	30,621,001,597	3.51	0	1.22	0	0.32	2.40
2100	23,603,319,566	2.90	0	0	0	0.09	1.85
2700	26,868,186,737	3.22	0	0.53	0.10	0	2.11
2900	751,649,736	0	0	1.89	0	0	0.20
Total	655,773,584,501	73.90	68.84	8.62	1.93	1.89	51.80

*High-weight, low-value commodity providing negligible contribution to overall value.

Effects of Key Commodities on Virginia's GSP

One way to estimate the importance of commodities' to a state is to look at the effect of each commodity on the state's GSP. As the majority of the commodities considered in this analysis are manufactured (SIC codes 2XXX and 3XXX), the effect of an individual commodity on the total and the manufacturing sectors of Virginia's GSP was considered. Table 7 shows the contribution of the key commodities to Virginia's total GSP and manufacturing sector of Virginia's GSP for 1997.

Virginia's key commodities account for a significant portion of the total weight and value of the freight shipped within Virginia. That fact, taken in conjunction with the fact that these commodities account for more than 11 percent and 80 percent of the overall and manufacturing GSPs, respectively, reveals that the key commodities can be considered important to Virginia's freight transportation system and its overall economy.

Freight Generation Analysis

Like conventional transportation planning techniques, freight forecasting also consists of four steps: freight generation, freight distribution, mode-choice analysis, and traffic assignment. The first step in forecasting future flows of freight is to complete a freight generation analysis by identifying the factors that affect the generation and attraction of freight in a given area. Changes in these generations and attractions can then be converted into flows between O-D pairs using freight distribution models, assigned to a particular mode, and finally assigned to the freight transportation network, completing the technical planning process. Completion of this technical planning process will signal the completion of the system inventory, allowing VDOT and the Virginia FAC to implement the remaining steps of that methodology.

Table 7. Virginia Gross State Product for Manufacturing in 1997 (SIC 2XXX and 3XXX)

Commodity	STCC Code	Dollar Value	% of Total GSP	% of Manufacturing GSP
Tobacco Products	*2100*	*4,581,000,000*	*2.17*	*14.64*
Chemicals & Allied Products	*2800*	*3,977,000,000*	*1.88*	*12.71*
Food & Kindred Products	*2000*	*3,414,000,000*	*1.62*	*10.91*
Electronic Equipment	*3600*	*2,335,000,000*	*1.10*	*7.46*
Printing & Publishing	*2700*	*2,105,000,000*	*1.00*	*6.73*
Motor Vehicles	*3700*	*1,687,000,000*	*0.80*	*5.39*
Paper Products	*2600*	*1,587,000,000*	*0.75*	*5.07*
Machinery, non-electrical	*3500*	*1,579,000,000*	*0.75*	*5.05*
Fabricated Metals	3400	1,524,000,000	0.72	4.87
Rubber & Plastics	*3000*	*1,490,000,000*	*0.71*	*4.76*
Textile Mill Products	2200	1,291,000,000	0.61	4.13
Lumber & Wood	*2400*	*1,288,000,000*	*0.61*	*4.12*
Other Transport. Equip.	3700	956,000,000	0.45	3.06
Furniture & Fixtures	2500	754,000,000	0.36	2.41
Instruments and Related Products	3800	687,000,000	0.33	2.20
Primary Metal Industries	3300	616,000,000	0.29	1.97
Stone, Clay, Glass	*3200*	*610,000,000*	*0.29*	*1.95*
Apparel & Textiles	*2300*	*470,000,000*	*0.22*	*1.50*
Miscellaneous Manufacturing	3900	203,000,000	0.10	0.65
Petroleum Products	*2900*	*104,000,000*	*0.05*	*0.33*
Leather Products	3100	25,000,000	0.01	0.08
Total		31,283,000,000	14.80	100

Items in italic are included on Virginia's key commodities list.

Overview

Many methods can be used to forecast changes in freight generations and attractions; one approach commonly used in the transportation profession is regression analysis. Regression analysis encompasses the identification of one or more independent, or "explanatory," variables that may influence the value of a dependent variable.[8] A mathematical relationship between the explanatory and dependent variables is defined, and growth in explanatory variables can then be used to forecast future growth of the dependent variable. Several regression techniques were used in this analysis, including ordinary least squares (OLS), robust, stepwise, and weighted least squares. A thorough discussion of regression analysis and its use in freight transportation planning is provided in NCHRP Report 388.[24]

OLS regression is the most commonly used form of regression analysis. Each observation is given equal importance (or weight) in the estimation of the regression coefficients.[24] A major drawback is that outliers in the data set can have a significant effect on the estimates of the regression coefficients.

Robust regression is an iterative method that can identify outliers and minimize their impacts on the final estimation of the regression coefficients. The robust regression procedure begins with an OLS regression. Using the regression coefficients calculated in the OLS regression, a set of residuals is calculated, each of which is assigned a "weight" between 0 and 1. An iterative process that includes performing OLS regressions and recalculating residuals is conducted until there is no change from one iteration to the next. The final set of robust weights can then be used to identify outliers in the data set. Observations with final robust weights less than 0.10 have little effect on the final regression model and are normally considered outliers. These outliers can be removed from the analysis and a weighted stepwise regression can be performed to determine which explanatory variables are most significant in the estimation of the dependent variable. Separate robust regressions can then be performed on the outliers to determine whether relationships exist between the dependent and explanatory variables in those observations.

When used in freight planning, regression analysis is used to develop equations that define the generation and attraction of freight in a given area. These generation and attraction equations are then used to predict future generations and attractions of freight in those areas.

Methodology

The following methodology was used to develop the freight generation and attraction relationships in this project:

1. Assign base year key commodity flows provided by the TRANSEARCH database to O-D matrices (one for each key commodity).

2. Define explanatory variables that may influence the value of freight generation/attraction.

3. Relate key commodity generation/attraction to these explanatory variables using various regression analysis techniques.

Assignment of Base Year Key Commodity Flows to O-D Matrices

This procedure involved a significant amount of data processing, the purpose of which was twofold. First, it reduced the size of the TRANSEARCH database, which originally contained more than 700,000 data records, to reflect only the flows of the key commodities identified in Table 4. Additionally, the data processing changed the format of the key commodity flow data, allowing O-D matrices to be more easily generated and manipulated.

The original TRANSEARCH database consists of two databases: one showing commodity flows into and out of Virginia, the other showing commodity flows traveling through Virginia. Freight generation and attraction relationships were developed only for counties and independent cities within Virginia, so only commodities with origins and/or destinations within Virginia were considered. Hence, the portion of the TRANSEARCH database showing commodity flows traveling through Virginia (neither originating nor terminating within Virginia) was not used in this phase of the analysis. To create statewide O-D matrices, queries were performed to isolate each of the 15 key commodities, the results of which were summarized and converted to matrix form.

Definition of Explanatory Variables

Preferred explanatory (i.e., independent) variables have the following characteristics:

- *Measurable.* Explanatory variables should consist of a quantitative measure that would affect the dependent variable.[25]
- *Independent.* Explanatory variables should be obtained through primary measurements and not derived from secondary data.[25]
- *Reliably forecast. S*ince growth in the explanatory variables will be used to estimate growth in the dependent variable, reliable forecasts for the variables should be available.

For the purposes of this study, the explanatory variables should also have the following characteristics:

- *Defined at the county/independent city level*. Since freight generation and attraction relationships are being developed at the county/independent city level, the explanatory variables should be defined at the same level of detail to ensure the accuracy of the regression analysis.
- *Readily available.* The freight generation and attraction relationships defined in this project will eventually be used by VDOT and the FAC in the statewide freight planning process. To make these relationships as user-friendly as possible, the explanatory variables and their forecasts should be easily obtainable (from public sources, if possible).

The typical explanatory variables used in freight transportation planning are population, which is assumed to affect the attraction of freight to an area, and industry employment, which is assumed to affect the generation of freight in an area. In addition to population and industry employment, Table 8 shows the explanatory variables used in this study.

These data meet all the criteria for explanatory variables. Though population and total employment are sometimes highly correlated, that is not the case in many Virginia cities and counties, particularly those in city/county pairs, such as Albemarle-Charlottesville. In these areas, population and total employment are often not very strongly correlated, as often times the area’s industry center is located in the independent city, whereas the population center may be located in the county. Thus, both variables were included in the regression analysis.

Table 8. Final Explanatory Variables

Explanatory Variable	Original Data Source	Forecast Source
Population	U.S. Bureau of Census	U.S. Bureau of Census
Industry Employment	IMPLAN Database	Virginia Employment Commission
Total Employment	IMPLAN Database	Virginia Employment Commission
Motor Freight & Warehousing Employment	IMPLAN Database	Virginia Employment Commission
Water Transportation Employment	IMPLAN Database	Virginia Employment Commission
Air Transportation Employment	IMPLAN Database	Virginia Employment Commission
Transportation Services Employment	IMPLAN Database	Virginia Employment Commission
County/City Size	U.S. Bureau of Census	U.S. Bureau of Census
Per Capita Income	U.S. Bureau of Census	U.S. Bureau of Census
Population Density	U.S. Bureau of Census	U.S. Bureau of Census
Daily Electric Coal Demand (Tons)	Dominion Virginia Power	Dominion Virginia Power
KW Capacity	Dominion Virginia Power	Dominion Virginia Power
Coal Tons/KW	Dominion Virginia Power	Dominion Virginia Power

Relating Key Commodity Generation/Attraction to Explain Variables

Two analyses for each key commodity were completed using the Number Cruncher Statistical System (NCSS): one to define freight generation relationships (using total originating tonnage as the dependent variable) and one to define freight attraction relationships (using total terminating tonnage as the dependent variable). The variables listed in Table 8 were used as the explanatory variables.

OLS regressions were performed first, but many potential outliers exist in the TRANSEARCH data set, especially the Port of Virginia, the Virginia Inland Port, and the many other modal transfer and LTL facilities in Virginia. These facilities often generate and attract significantly more freight than can be explained by the set of explanatory variables defined in Table 8. The results of the OLS regressions indicated the presence of these and other outliers, as the estimated regression coefficients were highly inflated and resulted in poor performance when these regression models were applied to "non-outliers."

To minimize the effects of these outliers, a series of weighted regressions were performed using the following methodology:

1. *Perform robust regression to identify first order outliers*. First order outliers were defined as those observations with final robust weights less than 0.10.

2. *Remove first order outliers from the analysis.* Using the NCSS's filter technique, these first order outliers were removed from the analysis, as they contributed little to the determination of the final regression coefficients.

3. *Perform weighted stepwise regression on non-outliers*. Using the final robust weights calculated, a weighted stepwise regression was performed on the non-outliers (final robust weights > 0.10) to determine the "best" regression model for these observations.

4. *Perform robust regression on outliers to identify second order outliers.* Attempts were made to identify relationships among the outliers and the independent variables by performing separate robust regressions on the outliers identified. As a result, second order outliers, or “outliers of the outliers” (robust weights less than 0.10), were identified and filtered from the analysis.

5. *Perform weighted stepwise regression on first* order *outliers*. A weighted stepwise regression was performed on the first order outliers with robust weights (calculated in the previous step) greater than 0.10 in order to determine the best regression model for these outliers. Relationships among the outliers were also identified and used to improve the final regression models. Examples of such relationships are total annual tonnage greater or less than a specified amount.

6. *Perform stepwise regression on second order outliers*. If second order outliers were present in the data, another stepwise regression was performed on these second order outliers to determine the best regression model.

Generation and Attractions Equations

This methodology yielded a set of generation and attraction regression equations for each two-digit STCC key commodity: for non-outliers, first order outliers, and second order outliers. A sample generation equation set is provided for STCC 3700 (transportation equipment) in Table 9.

Table 9. STCC 3700 (Transportation Equipment) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	102.97 (Industry Employment) – 0.0372 (Population) + 0.0679 (Total Employment) + 6.016 (Air Transportation Employment) + 45.028 (Transportation Services Employment)	96	0.9991
1st Order Outliers	24.907 (Industry Employment) – 0.1300 (Population) + 10.640 (Motor Freight & Warehouse Employment) + 399.69 (Water Transportation Employment) + 4.847 (Air Transportation Employment)	28	0.9963
2nd Order Outliers	105.09 (Industry Employment) + 1.062 (Total Employment)	12	0.6988
Overall adjusted R^2 = 0.9855			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	26.54 (Industry Employment) + 0.1396 (Population) – 0.0477 (Per Capita Income) + 0.1431 (Total Employment) + 217.2 (Water Transportation Employment) – 0.8206 (Air Transportation Employment) – 11.24 (Transportation Services Employment)	104	0.9999
1st Order Outliers	0.8336 (Population) – 2.811 (Industry Employment) + 1.762 (Total Employment) – 81.32 (Motor Freight and Warehouse Employment) + 126.7 (Air Transportation Employment) – 496.3 (Transportation Services Employment)	26	0.9936
2nd Order Outliers	0.4212 (Population)	6	0.9379
Overall adjusted R^2 = 0.9943			

The complete generation and attraction regression models for each of the 15 key commodities, along with their associated R^2 values, are provided in Appendix C. These equations provide an accurate picture of the generation and attraction of the key commodities in Virginia's counties and independent cities.

Freight Generation Equations

Successful regression equations were developed for 14 of the 15 key commodities. Successful equations for STCC 1400 (non-metallic ores and minerals) were not developed, indicating the generation of this commodity (at the county level) is not related to any of the explanatory variables listed in Table 8. Additionally, the regression equations produced for STCC 2400 (lumber or wood products) were only borderline successful, indicating that other explanatory variables may exist that better explain the generation of this commodity.

The most successful regression equations were those developed for low-weight, high-value commodities, such as STCCs 3700, 3600, and 3500 (transportation equipment, electrical machinery, and machinery, respectively). High-weight, low-value (bulk) commodities, including STCCs 2800, 2000, 3000, and 1400 (chemicals, food products, rubber or plastic products, and non-metallic minerals, respectively) were not so successfully modeled. This may be because many of these bulk commodity shipments take place on more than one transport mode and, in the course of these shipments, may make one or more intermediate stops at intermodal facilities or consolidation yards. These intermediate stops may skew the true O-Ds of these shipments and may explain why many of the outliers within these models are dependent upon motor freight and warehouse and transportation services employment levels. Identifying the locations of these intermediate facilities and the true O-Ds of these commodities may improve the overall precision of the regression equations. Another reason for the lower R^2 values for bulk commodities is that their generations may not be accurately described by the independent variables used in this analysis. Future researchers may wish to identify other factors that may influence the generation of these commodities.

Counties and cities were combined into single generation entities for five commodity groups: STCCs 2800, 3600, 3500, 2600, and 2700 (chemicals, electrical machinery, machinery, pulp or paper products, and printed matter, respectively). Of these five, three (STCCs 3600, 2700, and 2600) showed significant improvements in the overall performance of the freight generation models. Hence, counties and cities can be considered as single generators of STCC 3600, 2700, and 2600 freight.

Finally, it should be noted that these freight generation relationships are applicable only at the two-digit STCC level. The generation of individual four-digit commodities within these two-digit commodity groupings may be affected by other variables not considered in this project. Growth in the generation of a particular two-digit commodity grouping, then, may not be consistent with growth of each of the four-digit commodities within that grouping. Although a two-digit STCC level analysis may be appropriate for statewide planning, metropolitan planners may be more interested in the behavior of individual four-digit commodities and the factors that affect their generation and transportation. To understand the commodities within these two-digit commodity groupings and the forces that affect their generation and transportation, future researchers should disaggregate these (and other) commodities to a higher level of detail, i.e., to a three- or four-digit STCC level; identify their shipment characteristics; and determine what socioeconomic and market variables may affect their generation in Virginia.

Freight Attraction Equations

Successful attraction regression equations were developed for each of the 15 key commodities, most with higher adjusted R^2 values than the generation regression equations. This difference is most likely caused by the fact that particular commodities are generated in only particular areas whereas they are often attracted everywhere. This is particularly true for commodities whose production is dependent upon industry employment, such as STCCs 2000, 3000, 3200, 2400, and 1400 (food products; rubber or plastic products; clay, concrete, or glass; lumber or wood products; and non-metallic minerals, respectively). The attractions of these commodities are much easier to model, as they are normally affected by population or total employment.

For particular low-weight, high-value commodity groups, such as STCC 3500 (machinery), the attraction equation R^2 value was actually much lower than its generation R^2. This may be because certain four-digit commodities within these groups are driven by consumer demand whereas others may be used as inputs to secondary manufacturing processes. Future research should examine the disaggregation of this (and other) commodity group to determine which four-digit commodities are attracted to Virginia's diverse counties and cities and what factors contribute to the attractions. In addition, input-output modeling may help determine which of these commodities are consumer based and which are used in secondary manufacturing processes.

Counties and cities were combined and considered as single attraction entities for STCC 3700 (transportation equipment). As the overall R^2 value for these new models did not improve, however, the attraction of STCC 3700 freight should be considered separately in Virginia cities and counties.

Finally, it should be noted that these freight attraction relationships are applicable only at the two-digit STCC level. The attraction of individual four-digit commodities within these two-digit commodity groupings may be affected by other variables not considered in this project. Growth in the attraction of a particular two-digit commodity grouping, then, may not be consistent with growth of each of the four-digit commodities within that grouping. Although a two-digit STCC level analysis may be appropriate for statewide planning, metropolitan planners may be more interested in the behavior of individual four-digit commodities and the factors that affect their attraction and transportation. To understand the commodities within these two-digit commodity groupings and the forces that affect their attraction and transportation, future researchers should disaggregate these (and other) commodities to a higher level of detail, i.e. to a three- or four-digit STCC level; identify their shipment characteristics; and determine what socioeconomic and market variables may affect their attraction in Virginia.

Completion of Technical Planning Process

The proposed four-step freight transportation modeling process predicts future freight using the trip generation equations for generations and attractions, which are then distributed between O-D pairs using traditional trip distribution models, assigned to a mode, and routed along the freight transportation network. This section describes trip distribution models used in freight transportation planning and provides a demonstration of the use of one of these models to distribute future flows of a single commodity between existing Virginia O-D pairs. Potential freight transportation mode choice and traffic assignment techniques are also discussed.

Trip Distribution

Gravity Model

A popular method used in trip distribution is the Gravity Model. This model, based on the gravitational theory of Newtonian physics, states that the number of trips between two areas is directly proportional to the number of productions and attractions in each area and inversely proportional to the travel time (or impedance) between the areas.[27] In freight transportation planning, the number of trips is replaced by the number of tons of a particular commodity traveling between two areas. The Gravity Model is mathematically defined as follows:

$$T_{kij} = TO_{ki} TD_{kj} F_{ij} / \sum_{j=1}^{n} TD_{kj} F_{ij}$$

where T_{kij} = tons of commodity k traveling from zone i to j

TO_{ki} = tons of commodity k origination at zone I

TD_{kj} = tons of commodity k destined for zone j

F_{ij} = the impedance factor from i to j.

Common impedance factors used in the Gravity Model are those that quantify the separation between areas, such as distance or the inverse of travel time. These factors are normally calibrated using an iterative process, where successive results are compared to O-D surveys[28] or are smoothed using the gamma function.[27]

Because of the nature of freight travel, the use of the model to distribute future freight flows at a statewide level is difficult. Unlike passenger transportation, which mainly occurs on a single mode (automobile), freight transportation has a varied modal split among truck, rail, water, and air. Although the truck mode is still dominant (accounting for 80 percent of all key commodity movements by weight), some commodity groups, including STCC 1400 (non-metallic minerals), are not transported by truck. For this reason, impedance factors are difficult to calculate, as different impedance factors must be developed for each mode and for movements between modes. Impedance factors for the trucking mode, for example, must not only consider spatial separation between zones, but must also account for highway truck height and weight restrictions; for rail movements, weight capacity and the number of sidings should be considered.

Further complicating the development of impedance factors for use in a traditional Gravity Model are the diverse shipment characteristics of different commodities. Unlike passengers, all freight shipments cannot be considered to share similar travel properties. High-value, low-weight freight is often time sensitive and would be more likely to move by truck on interstate highways. Conversely, time is not so critical for low-value, high-weight shipments, which may be more likely to move on the rail or water modes or on highway routes that minimize the distance between two areas. Finally, trucked commodities traveling in LTL shipments often make one or more intermediate stops at trans-shipment facilities prior to arriving at their final destinations. Rail and water shipments also often change modes. These intermediate stops can be considered as separate O-Ds for every LTL and intermodal shipment, further complicating the trip distribution process.

Fratar Growth Factor Model

Description. A simple method by which future freight flows can be distributed between O-D pairs is the Fratar Growth Factor Model. This model was widely used in passenger transportation planning when O-D data were available but before the impedance factor calibration process had been perfected.[28] In freight transportation planning, the model can be used to distribute future tons of a particular commodity traveling between existing O-D pairs. The model is mathematically defined as follows:

$$T_{ij} = (T_i G_i)\left[t_{ij} G_j / \sum_x t_{ix} G_x \right]$$

where T_{ij} = tons of a particular commodity estimated from zone *i* to *j*

t_i = present number of tons generated in and attracted to zone *i* (trip ends)

$T_i = t_i G_i$ = future number of tons produced in and attracted to zone *i* (future trip ends)

t_{ij} = present number of tons traveling between zones *i* and *j*

G_j = growth factor for zone *j*.

This model is iterated and growth factors are refined until the ratio of the estimated trip generation to the calculated trip generation equals 1.

The Fratar Model is essentially a complex extrapolation method and should be viewed as a potential method for distributing future freight flows but as one that requires future study to determine its suitability. First, it is dependent on an existing O-D matrix, so, unlike the Gravity Model, it cannot be used to forecast freight movements where no movements currently exist. In addition, it does not consider impedances between areas; it simply considers future freight movements between areas as a product of the current trips between them. Finally, the model distributes trip ends, not trips. Trip ends are simply the sums of the generations and attractions in an area. To ensure balance, future trip ends are equally divided between O-D pairs, regardless of their original proportion. When using a Fratar Model, then, the number of attractions in an area will always equal the number of productions. This is a particularly unrealistic assumption in freight transportation, as different commodities are rarely produced in and attracted to areas in equal amounts.

Despite its limitations, the Fratar Growth Model is a simple trip distribution method that provides an initial attempt to future flows of freight between existing O-D pairs and will be used to demonstrate the freight trip distribution process.

Demonstration. A single commodity, STCC 3700 (transportation equipment), was selected to demonstrate the use of a Fratar Growth Factor Model to distribute future freight flows. STCC 3700 was selected because of its highly accurate generation and attraction equations (R^2 values of 0.9855 and 0.9943, respectively), which were used to provide predictions of future STCC 3700.

1. Determination of current trip ends in each zone (t_i). In this application, the total tons of STCC 3700 freight originating and terminating in each county and independent city for the base year, taken from the O-D tables developed for each key commodity, were added to arrive at the total trip ends in each zone.

2. Determination of future trip-ends in each zone (T_i). Using the freight production and attraction equations developed with 5-year estimates of employment and population, future trip ends of STCC 3700 were calculated for each zone. Population and employment estimates were not available for areas outside Virginia, so the population and employment growth in these areas was assumed to be the same as the growth within Virginia.

3. Determination of Tons Traveling Between Zones (t_{ij}). This value can be determined using the O-D tables developed for each key commodity. In this demonstration, the STCC 3700 O-D table provided the tons traveling between each O-D pair.

4. Determination of growth factors (G_x). The initial growth factors for each zone in Virginia were calculated using the generation and attraction equations developed with 5-year estimates of employment and population. Again, since population and employment estimates were not as readily available for zones outside Virginia, an initial growth factor of 1.0 was assumed for these areas. With each iteration of the Fratar Model, a new set of growth factors was calculated and used in the subsequent iteration.

5. Final distribution of 5-year projection of STCC 3700 Freight. Iterations were repeated until the calculated growth factors were within 0.5 percent of the growth factors calculated by the previous iteration. Table 10 shows a sample of the resulting O-D matrix (after three iterations) for the final 5-year distribution of STCC 3700 freight (original values in parentheses).

Table 10. Partial Final Distribution for 5-year Estimate of STCC 3700 Freight

T_{ij}	Destination Region = 1	2	3	4	5	6	7
Origin Region=1	0	0	0	0	0	0	295 (275)
2	0	0	0	0	0	0	285 (259)
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
7	295 (275)	285 (259)	0	0	0	0	1,862 (870)
8	0	0	0	0	0	0	1,361 (1,223)
9	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0

Mode Choice Analysis

Freight distribution models, including the Gravity and Fratar Growth Factor Models, distribute total freight flows between O-D pairs. The next step in the freight planning process is to allocate these total flows among the various transportation modes.

In passenger transportation, mode choice is a complex modeling process that often depends on the actual and perceived advantages of each mode in terms of travel time, cost, comfort, convenience, and safety.[28] Freight transportation mode choice analysis must also consider the relative costs and service levels of the different modes and the unique shipment characteristics (including weight, value, and time sensitivity) of each commodity being modeled. Most existing freight mode choice models use transport or logistics costs as the primary factor in allocating freight movements among modes.[29] The rise of "just in time" inventory practices, LTL motor freight carriers, and intermodal movements, however, has complicated the freight transportation mode choice process and may not be reflected in existing freight mode choice models. Future research should be conducted to develop accurate mode choice models for each of Virginia's 15 key commodities.

Traffic Assignment

After a mode choice analysis is performed, commodity movements (in tons) must then be assigned to vehicle equivalents. These vehicles can then be assigned to the existing transportation network using an all-or-nothing or capacity-restrained assignment process. Future researchers should develop ton-to-vehicle conversion factors for each key commodity and identify impedance factors with which to complete an all-or-nothing or capacity-restrained traffic assignment.

CONCLUSIONS

General

The work completed in this project advances the completion of the system inventory step of the Statewide Intermodal Freight Transportation Planning Methodology, allowing further implementation of the remaining steps. The products of this project, including the FAC, the freight transportation GIS database, key commodity flow data, and freight generation and attraction relationships, can be immediately used by VDOT to help quantify the movement of freight into, out of, and through Virginia and to understand freight's role in the overall transportation system. In addition, this methodology is transferable to other states to use to complete inventories of their own freight transportation systems in the course of their own freight planning programs.

Although freight transportation has unique characteristics that make its distribution difficult to model using traditional passenger transportation planning techniques, the Fratar Growth Model may provide a good initial estimation of the distribution of future freight flows among existing O-Ds, especially in the absence of calibrated impedance factors for use in a Gravity Model. Future researchers should investigate alternative distribution methods, including modified Gravity or Fratar Growth Factor models, by which to estimate the distribution of future freight flows.

Finally, to complete the traditional planning process, future researchers should develop freight transportation mode choice models and ton-to-vehicle conversion factors and use these tools to assign future freight flows to Virginia's existing freight transportation network to assist VDOT and the FAC to continue with the intermodal freight transportation planning methodology proposed in Phase I of this project.[1]

Specific

- The system inventory of the Statewide Intermodal Freight Transportation Planning Methodology when implemented using the TRANSEARCH commodity flow database provides the analytical framework for statewide freight transportation planning.
- Robust regression is an appropriate tool to model freight production and attraction, particularly when outliers are in the dataset.
- Several socioeconomic variables significantly affect the generation and attraction of freight.
- Freight attraction models are more accurate than freight generation models at the two-digit STCC level.

- Large amounts of freight originate and/or terminate at the Port of Virginia, hindering attempts to develop accurate freight generation and attraction relationships using commodity flow data from the TRANSEARCH database.

RECOMMENDATIONS

1. *VDOT's TPD should integrate the application of the inventory methodology for solving freight -related infrastructure problems and the FAC's involvement in the freight transportation planning process.* As much of the freight transportation expertise resides in the private sector, its involvement in the freight planning process is crucial. VDOT should continue to sponsor FAC meetings and encourage the discussion of statewide freight transportation issues and concerns.

2. *VDOT's TPD, in consultation with the FAC, should use the Statewide Intermodal Freight Transportation Planning Methodology to address freight transportation problems and develop potential alternatives.* Using this information developed in this study, VDOT, in consultation with the FAC, should identify current and potential problems on Virginia's freight transportation system and use remaining steps of the Statewide Intermodal Freight Transportation Planning Methodology to address them.

3. *VDOT's TPD should use the spatial analysis functions of the freight transportation GIS database as a freight planning tool.* The database developed in this project is used mainly as a module with which to display key commodity flows moving along Virginia's freight transportation network. Although this display function allows easy identification of current and potential bottlenecks, the spatial analysis utilities of the GIS are not so well used. These utilities could help VDOT determine where to locate intermodal facilities to take advantage of current freight flows. Additionally, the land use, population, and employment information included in the database could be used to determine the safest route for shipping hazardous material.

4. *VDOT's TPD should consider purchasing updated commodity flow data.* Since the volume and types of commodities traveling into, out of, and through Virginia will change over time, VDOT should consider purchasing updated commodity flow data. These data can be used to validate and refine the freight production and attraction models developed in this project and allow VDOT and the FAC to stay abreast of changes in the nature of freight movements throughout Virginia.

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APPENDIX A

TWO-DIGIT STANDARD CLASSIFICATION OF TRANSPORTED GOOD (SCTG) CODES AND DESCRIPTIONS

SCTG Code	Description
0100	Live animals
0200	Cereal grains
0300	Agricultural products, except cereal grains
0400	Animal feed, pet food, and products of animal origin
0500	Meat, fish, and preparations
0600	Milled grain products and preparations, and bakery products
0700	Prepared foods
0800	Alcoholic beverages
0900	Tobacco products and substitutes
1000	Monumental or building stone
1100	Gravel and crushed stone
1200	Natural sands
1300	Non-metallic minerals
1400	Metallic ores
1500	Coal
1600	Crude petroleum
1700	Gasoline and aviation turbine fuel
1800	Fuel oils
1900	Refined petroleum products
2000	Basic chemicals
2100	Pharmaceutical products
2200	Fertilizers
2300	Chemical products and preparations
2400	Plastics and rubber
2500	Forest products
2600	Wood products
2700	Pulp, newsprint, paper, and paperboard
2800	Converted paper and converted paper products
2900	Printed products
3000	Textiles, leather, and articles
3100	Non-metallic mineral products
3200	Iron and steel in primary forms and basic shapes
3300	Metal except iron and steel, and articles of metal
3400	Mechanical machinery
3500	Computer equipment and software
3600	Electrical machinery and equipment
3700	Vehicles
3800	Engines, parts, and accessories for vehicles
3900	Transportation equipment
4000	Precision instruments and apparatus
4100	Furniture and furnishings
4200	Miscellaneous manufactured products
4300	Waste and scrap

APPENDIX B

TWO-DIGIT STANDARD TRANSPORTATION COMMODITY CLASSIFICATION (STCC) CODES AND DESCRIPTIONS

STCC Code	Description
0100	Farm products
0800	Forest products
0900	Fresh Fish
1000	Metallic ores
1100	Coal
1300	Crude petroleum, natural gas or gasoline
1400	Nonmetallic ores, minerals, excluding fuels
1900	Ordnance or accessories
2000	Food and kindred products
2100	Tobacco products, excluding insecticides
2200	Textile mill products
2300	Apparel or other finished textile products or knit apparel
2400	Lumber or wood products, excluding furniture
2500	Furniture or fixtures
2600	Pulp, paper, or allied products
2700	Printed matter
2800	Chemicals or allied products
2900	Petroleum or coal products
3000	Rubber or miscellaneous plastics products
3100	Leather or leather products
3200	Clay, concrete, glass, or stone products
3300	Primary metal products
3400	Fabricated metal products
3500	Machinery, excluding electrical
3600	Electrical machinery, equipment, or supplies
3700	Transportation equipment
3800	Instruments, photographic goods, optical goods, watches or clocks
3900	Miscellaneous products of manufacturing
4000	Waste or scrap materials not identified by producing industry
4100	Miscellaneous freight shipments
4200	Containers, carriers or devices, shipping, returned empty
4300	U.S. Postal Service shipments
4600	Mixed freight shipments

APPENDIX C

FREIGHT GENERATION AND ATTRACTION EQUATIONS

STCC 3700 (Transportation Equipment) Freight Generation and Attraction Equations

Model	**Generation Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	102.97 (Industry Employment) – 0.0372 (Population) + 0.0679 (Total Employment) + 6.016 (Air Transportation Employment) + 45.028 (Transportation Services Employment)	96	0.9991
1st Order Outliers	24.907 (Industry Employment) – 0.1300 (Population) + 10.640 (Motor Freight & Warehouse Employment) + 399.69 (Water Transportation Employment) + 4.847 (Air Transportation Employment)	28	0.9963
2nd Order Outliers	105.09 (Industry Employment) + 1.062 (Total Employment)	12	0.6988
Overall Adjusted R^2 = 0.9855			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	26.54 (Industry Employment) + 0.1396 (Population) – 0.0477 (Per Capita Income) + 0.1431 (Total Employment) + 217.2 (Water Transportation Employment) – 0.8206 (Air Transportation Employment) – 11.24 (Transportation Services Employment)	104	0.9999
1st Order Outliers	0.8336 (Population) – 2.811 (Industry Employment) + 1.762 (Total Employment) – 81.32 (Motor Freight and Warehouse Employment) + 126.7 (Air Transportation Employment) – 496.3 (Transportation Services Employment)	26	0.9936
2nd Order Outliers	0.4212 (Population)	6	0.9379
Overall Adjusted R^2 = 0.9943			

STCC 2800 (Chemicals or Allied Products) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	151.35 (Industry Employment) – 0.1456 (Population) + 0.6105 (Total Employment) – 2.227 (Population Density) – 6.467 (Motor Freight & Warehouse Employment) + 8.743 (Water Transportation Employment) – 43.890 (Transportation Services Employment)	94	0.9924
1st Order Outliers (< 200K Tons)	126.23 (Motor Freight & Warehouse Employment) – 315.50 (Water Transportation Employment)	29	0.6399
1st Order Outliers (> 200K Tons)	18.573 (Per Capita Income) - 1.726 (Population) – 0.2657 (Total Employment) + 1662.04 (Transportation Services Employment)	13	0.9971
Overall Adjusted R^2 = 0.8587			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers (< 1,000 Tons)	0.0621 (Total Employment) – 0.0039 (Per Capita Income)	41	0.6077
Non-Outliers (> 1,000 Tons)	119.25 (Industry Employment) + 10.92 (County Size) + 1.227 (Total Employment) – 38.23 (Motor Freight and Warehouse Employment) + 121.72 (Water Transportation Employment) – 17.41 (Air Transportation Employment) + 129.10 (Transportation Services Employment)	63	0.9941
1st Order Outliers	3.300 (Population) + 1.100 (Per Capita Income) – 107.1 (Motor Freight and Warehouse Employment) + 619.3 (Air Transportation Employment) – 1,276 (Transportation Services Employment)	32	0.9755
Overall Adjusted R^2 = 0.8875			

STCC 3600 (Electrical Machinery, Equipment, or Supplies) Freight Generation and Attraction Equations

Model	**Generation Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	5.255 (Industry Employment) – 0.0035 (Population) + 0.0079 (Total Employment) – 2.227 (Population Density) – 0.1574 (Motor Freight & Warehouse Employment) – 2.073 (Water Transportation Employment) + 0.1774 (Air Transportation Employment) + 12.564 (Transportation Services Employment)	95	0.9976
1st Order Outliers	4.955 (Industry Employment) – 6.058 (County Size) + 0.0973 (Total Employment) + 19.85 (Water Transportation Employment)	41	0.9143
Overall Adjusted R^2 = 0.9167			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	2.581 (Industry Employment) – 0.0228 (Population) + 0.0665 (Total Employment) + 0.0759 (Population Density) + 1.699 (Water Transportation Employment) + 4.635 (Air Transportation Employment) + 31.36 (Transportation Services Employment)	100	0.9974
1st Order Outliers	11.34 (Motor Freight and Warehouse Employment)	33	0.8336
2nd Order Outliers	2.800 (Total Employment) – 1.312 (Population)	3	0.9999
Overall Adjusted R2 = 0.9962			
Model	**Generation Equation (Combined Cities & Counties)**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	8.379 (Industry Employment) – 0.0007 (Population) – 0.9555 (Population Density) – 0.1302 (Motor Freight and Warehouse Employment) – 0.3844 (Water Transportation Employment) + 1.076 (Air Transportation Employment) + 18.97 (Transportation Services Employment)	74	0.9998
1st Order Outliers	0.0834 (Population) + 4.054 (Population Density) + 15.99 (Water Transportation Employment)	20	0.9896
2nd Order Outliers	5.555 (Industry Employment)	10	0.5861
Overall Adjusted R2 = 0.9662			

STCC 3500 (Machinery, excluding Electrical) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	6.511 (Industry Employment) – 0.1205 (Population) – 0.0413 (Per Capita Income) + 0.3211 (Total Employment) + 106.55 (Water Transportation Employment) – 2.378 (Air Transportation Employment) + 30.43 (Transportation Services Employment)	109	0.9952
1st Order Outliers	212.47 (Water Transportation Employment) – 0.0777 (Population)	22	0.9940
2nd Order Outliers	38.21 (Industry Employment)	5	0.7536
Overall Adjusted R^2 = 0.9870			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	1.507 (Industry Employment) – 0.0136 (Population) – 0.0126 (Per Capita Income) + 0.0356 (Total Employment) + 0.1114 (Population Density) + 0.3963 (Motor Freight and Warehouse Employment) + 8.027 (Water Transportation Employment) + 9.622 (Air Transportation Employment) + 58.99 (Transportation Services Employment)	105	0.9994
1st Order Outliers	1.052 (Population)	23	0.8433
2nd Order Outliers	12.37 (Motor Freight and Warehouse Employment)	8	0.9050
Overall Adjusted R^2 = 0.8319			

STCC 2000 (Food and Kindred Products) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	175.25 (Industry Employment) + 355.95 (Water Transportation Employment) + 7.478 (Air Transportation Employment)	96	0.9926
1st Order Outliers (< 40,000 Tons)	5.607 (Industry Employment) + 0.0731 (Per Capita Income) + 9.144 (Population Density) + 118.00 (Water Transportation Employment)	12	0.9298
1st Order Outliers (> 40,000 Tons)	104.16 (Industry Employment)	24	0.6692
2nd Order Outliers	362.14 (Industry Employment)	4	0.8541
Overall Adjusted R^2 = 0.8122			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers (< 1,000 Tons)	0.0630 (Population)	19	0.8233
Non-Outliers (> 1,000 Tons)	43.52 (Industry Employment) + 0.2393 (Population) – 0.2420 (Per Capita Income) + 0.4825 (Total Employment) + 3.610 (Motor Freight and Warehouse Employment) + 50.07 (Water Transportation Employment) – 9.433 (Transportation Services Employment)	80	0.9984
1st Order Outliers	7.198 (Industry Employment) – 0.2851 (Per Capita Income) + 1.939 (Total Employment)	30	0.9800
2nd Order Outliers	3.107 (Per Capita Income) + 11,025 (Transportation Services Employment)	7	0.9637
Overall Adjusted R^2 = 0.9688			

STCC 2600 (Pulp, Paper, or Allied Products) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	194.14 (Industry Employment) – 0.2755 (Population) – 0.0332 (Per Capita Income) + 0.5788 (Total Employment) – 1.146 (Population Density) + 97.55 (Water Transportation Employment) – 7.242 (Air Transportation Employment) + 79.23 (Transportation Services Employment)	99	0.9985
1st Order Outliers	145.02 (Industry Employment) + 75.42 (Motor Freight & Warehouse Employment)	26	0.9682
2nd Order Outliers	2.932 (Population) + 383.6 (Air Transportation Employment)	11	0.7187
Overall Adjusted R^2 = 0.8061			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers (< 1,000 Tons)	0.0750 (Population)	16	0.8724
Non-Outliers (> 1,000 Tons)	16.57 (Industry Employment) – 0.3742 (Population) + 1.367 (Total Employment) + 5.996 (Motor Freight and Warehouse Employment) + 40.58 (Water Transportation Employment) – 21.09 (Air Transportation Employment) + 408.0 (Transportation Services Employment)	82	0.9988
1st Order Outliers	3.436 (Total Employment)	38	0.8312
Overall Adjusted R^2 = 0.8355			

Model	Generation Equation (with Combined Cities and Counties)	No. of Observations	Adjusted R^2
Non-Outliers	234.0 (Industry Employment) – 0.2560 (Population) + 0.5503 (Total Employment) – + 0.6737 (County Size) – 5.586 (Population Density) + 118.0 (Water Transportation Employment) – 3.517 (Air Transportation Employment) + 34.48 (Transportation Services Employment)	74	0.9998
1st Order Outliers	147.3 (Industry Employment) – 3.860 (Total Employment) + 380.9 (County Size) – 5.256 (Per Capita Income) + 34.87 (Population Density) + 76.48 (Motor Freight & Warehouse Employment) + 748.6 (Air Transportation Employment) + 900.8 (Transportation Services Employment)	20	0.9985
2nd Order Outliers	271.8 (Industry Employment)	10	0.7619
Overall Adjusted R^2 = 0.9406			

STCC 3000 (Rubber or Miscellaneous Plastics Products) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	54.97 (Industry Employment) – 0.0209 (Population) + 0.0637 (Total Employment) – 0.7805 (Motor Freight & Warehouse Employment) + 9.851 (Water Transportation Employment) – 1.107 (Air Transportation Employment) – 5.259 (Transportation Services Employment)	85	0.9982
1st Order Outliers	30.93 (Industry Employment) + 18.38 (County Size (in square miles)) + 0.3974 (Per Capita Income) + 55.11 (Water Transportation Employment)	39	0.9249
2nd Order Outliers	32.04 (Industry Employment) + 0.3663 (Per Capita Income) + 49.77 (Population Density)	12	0.5196
Overall Adjusted R^2 = 0.6642			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	0.2434 (Total Employment) – 0.0552 (Population) – 2.432 (County Size) – 0.0055 (Per Capita Income) – 0.2346 (Population Density) + 3.787 (Motor Freight and Warehouse Employment) – 5.918 (Water Transportation Employment) + 11.19 (Air Transportation Employment) + 28.71 (Transportation Services Employment)	98	0.9958
1st Order Outliers	1.450 (Population) + 0.6245 (Total Employment) – 71.77 (Motor Freight and Warehouse Employment) + 159.05 (Water Transportation Employment) – 41.78 (Air Transportation Employment) – 288.2 (Transportation Services Employment)	28	0.9894
2nd Order Outliers	22.39 (Industry Employment) + 20.09 (Motor Freight and Warehouse Employment)	10	0.3414
Overall Adjusted R^2 = 0.9773			

STCC 3200 (Clay, Concrete, Glass, or Stone Products) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	491.88 (Industry Employment) – 0.1683 (Per Capita Income) + 351.03 (Water Transportation Employment) + 8.268 (Air Transportation Employment) + 168.31 (Transportation Services Employment)	101	0.9794
1st Order Outliers	5.996 (Population) – 2256.3 (Transportation Services Employment)	23	0.9253
2nd Order Outliers	3362.0 (Industry Employment)	12	0.7791
Overall Adjusted R^2 = 0.8214			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers (< 6,000 Tons)	0.4712 (Population)	14	0.9384
Non-Outliers (> 6,000 Tons)	48.47 (Industry Employment) + 0.6175 (Population) – 0.6690 (Per Capita Income) + 3.275 (Total Employment) – 32.96 (Motor Freight and Warehouse Employment) + 188.1 (Water Transportation Employment) + 48.87 (Air Transportation Employment) + 111.6 (Transportation Services Employment)	90	0.9985
1st Order Outliers	8.065 (Population) – 177.1 (Motor Freight and Warehouse Employment) – 123.5 (Air Transportation Employment)	32	0.9560
Overall Adjusted R^2 = 0.9587			

STCC 2400 (Lumber or Wood Products, excluding Furniture) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	506.69 (Industry Employment) – 1.217 (Population) + 0.0334 (Per Capita Income) + 3.235 (Total Employment) – 78.716 (Motor Freight & Warehouse Employment) – 12.792 (Air Transportation Employment)	114	0.9325
1st Order Outliers	560.4 (Industry Employment)	22	0.7672
Overall Adjusted R^2 = 0.5349			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers (<10,000 Tons)	0.4847 (Population)	24	0.8952
Non-Outliers (> 10,000 Tons)	17.96 (Industry Employment) + 2.377 (Total Employment) – 5.841 (Population Density) + 15.35 (Motor Freight and Warehouse Employment) – 23.22 (Air Transportation Employment) + 138.4 (Transportation Services Employment)	84	0.9926
1st Order Outliers (<700,000 Tons)	2.228 (Total Employment) + 545.8 (Water Transportation Employment)	24	0.7630
1st Order Outliers (> 700,000 Tons)	10.06 (Total Employment)	4	0.9717
Overall Adjusted R^2 = 0.9091			

STCC 1100 (Coal) Freight Generation Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	5278.3 (Industry Employment)	7	0.9641
1st Order Outliers	Note: Only 7 counties in Virginia produce coal.	N/A	N/A
Overall Adjusted R^2 = 0.9632			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	32.63 (Industry Employment) + 4.969 (Population Density) + 98.69 (Water Transportation Employment) + 460.63 (Daily Electric Coal Demand) + 0.4212 (KW Capacity) – 717.9 (Coal Tons/KW)	104	0.9999
1st Order Outliers (<500,000 Tons)	100.7 (Motor Freight and Warehouse Employment) – 0.3369 (Total Employment) – 20.98 (Industry Employment)	26	0.9999
1st Order Outliers (> 500,000 Tons)	2950 (County Size) – 109.3 (Motor Freight and Warehouse Employment) + 6121 (Water Transportation Employment)	6	0.9976
Overall Adjusted R^2 = 0.9972			

STCC 1400 (Non-metallic Ores, Minerals, excluding Fuels) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	0.00078 (Total Employment) – 0.0065 (Population) – 0.1394 (Population Density) + 506.14 (Water Transportation Employment) + 6.207 (Air Transportation Employment) – 34.417 (Transportation Services Employment)	86	0.9999
1st Order Outliers	282.57 (Industry Employment) – 0.0274 (Population) + 0.0876 (Total Employment) – 5.151 (Motor Freight and Warehouse Employment) – 6.870 (Air Transportation Employment)	33	0.9306
2nd Order Outliers	1509.2 (Industry Employment)	17	0.3081
Overall Adjusted R^2 = 0.4428			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers (<19,000 Tons)	18.43 (County Size)	8	0.8977
Non-Outliers (> 19,000 Tons)	6.742 (Total Employment)	4	0.9976
1st Order Outliers (<50,000 Tons)	58.02 (County Size) – 4.871 (Motor Freight and Warehouse Employment)	7	0.4388
1st Order Outliers (> 50,000 Tons)	1218 (Motor Freight and Warehouse Employment) – 0.7598 (Per Capita Income) – 1914 (Water Transportation Employment)	11	0.9772
Overall Adjusted R^2 = 0.9631			

STCC 2300 (Apparel or other Finished Textile Products or Knit Apparel) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R2
Non-Outliers	6.659 (Industry Employment) – 0.0331 (Population) – 0.0023 (Per Capita Income) + 0.0404 (Total Employment) + 2.224 (Motor Freight and Warehouse Employment) + 14.52 (Water Transportation Employment) – 0.3265 (Air Transportation Employment) + 2.463 (Transportation Services Employment)	106	0.9759
1st Order Outliers	12.63 (Industry Employment) + 19.04 (Water Transportation Employment) + 9.168 (Air Transportation Employment)	30	0.8846
Overall Adjusted R^2 = 0.8548			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	0.0083 (Population) – 0.1816 (County Size) – 0.0049 (Total Employment) – 0.3240 (Motor Freight and Warehouse Employment) – 6.341 (Water Transportation Employment) + 1.193 (Air Transportation Employment)	97	0.9968
1st Order Outliers	0.7862 (Total Employment) – 8.638 (Population Density) – 25.41 (Motor Freight and Warehouse Employment) – 9.975 (Air Transportation Employment)	39	0.9124
Overall Adjusted R^2 = 0.9399			

STCC 2100 (Tobacco Products, excluding Insecticides) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	4.984 (Industry Employment) + 83.22 (Water Transportation Employment)	12	0.8939
Overall Adjusted R^2 = 0.8939			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	0.1761 (Industry Employment) + 0.0196 (Population) – 0.2018 (County Size) – 0.0132 (Per Capita Income) + 0.0197 (Total Employment) + 0.1313 (Motor Freight and Warehouse Employment) + 0.7810 (Water Transportation Employment) – 0.1534 (Air Transportation Employment) + 0.6811 (Transportation Services Employment)	111	0.9971
1st Order Outliers (< 10,000 Tons)	7.640 (Industry Employment) + 5.186 (Motor Freight and Warehouse Employment) – 3.682 (Air Transportation Employment)	20	0.8005
1st Order Outliers (>10,000 Tons)	0.1541 (Population)	5	0.9361
Overall Adjusted R^2 = 0.9330			

STCC 2700 (Printed Matter) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	12.29 (Industry Employment) – 0.0793 (Population) + 0.1916 (Total Employment) – 1.610 (Motor Freight & Warehouse Employment) – 5.567 (Water Transportation Employment) + 46.34 (Transportation Services Employment)	104	0.9974
1st Order Outliers	16.48 (Industry Employment) – 12.12 (County Size) + 1.409 (Population Density)	21	0.9119
2nd Order Outliers	494.9 (Transportation Services Employment)	11	0.8304
Overall Adjusted R^2 = 0.9014			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	0.5278 (Industry Employment) + 0.0155 (Population) – 0.3684 (County Size) – 0.0193 (Per Capita Income) + 0.0603 (Total Employment) – 0.5699 (Motor Freight and Warehouse Employment) + 2.291 (Water Transportation Employment) + 5.173 (Air Transportation Employment) + 8.587 (Transportation Services Employment)	110	0.9971
1st Order Outliers	81.00 (Industry Employment) – 21.92 (Air Transportation Employment) + 137.9 (Transportation Services Employment)	19	0.9326
2nd Order Outliers	4.154 (Industry Employment) + 0.1061 (Total Employment)	7	0.9846
Overall Adjusted R^2 = 0.9318			

Model	Generation Equation (with Combined Cities and Counties)	No. of Observations	Adjusted R^2
Non-Outliers	11.01 (Industry Employment) – 0.1200 (Population) + 0.2096 (Total Employment) + 0.9473 (Population Density) + 4.668 (Motor Freight & Warehouse Employment) – 2.228 (Water Transportation Employment) – 3.086 (Air Transportation Employment) + 38.01 (Transportation Services Employment)	82	0.9994
1st Order Outliers	14.46 (Industry Employment) + 16.57 (Air Transportation Employment)	17	0.9717
2nd Order Outliers	34.02 (Motor Freight and Warehouse Employment) – 3.425 (County Size)	5	0.8560
Overall Adjusted R^2 = 0.9893			

STCC 2900 (Petroleum or Coal Products) Freight Generation and Attraction Equations

Model	Generation Equation	No. of Observations	Adjusted R^2
Non-Outliers	4155.5 (Industry Employment) – 0.0361 (Population) + 0.0608 (Total Employment) – 0.2044 (Population Density) + 1.789 (Motor Freight & Warehouse Employment) + 364.03 (Water Transportation Employment) – 46.65 (Transportation Services Employment)	88	0.9999
1st Order Outliers	10,610 (Industry Employment) + 0.4296 (Population) – 0.5647 (Per Capita Income) – 124.63 (Motor Freight and Warehouse Employment) + 959.2 (Water Transportation Employment) + 105.49 (Air Transportation Employment)	42	0.9966
2nd Order Outliers	173,820 (Water Transportation Employment) + 30.21 (Per Capita Income) – 24,650 (Industry Employment)	6	0.6859
Overall Adjusted R^2 = 0.9199			
Model	**Attraction Equation**	**No. of Observations**	**Adjusted R^2**
Non-Outliers	0.0994 (Population) – 704.7 (Industry Employment) – 0.1584 (Per Capita Income) + 0.8942 (Total Employment) – 1.256 (Population Density) + 295.0 (Water Transportation Employment) – 34.53 (Air Transportation Employment) + 372.5 (Transportation Services Employment)	102	0.9997
1st Order Outliers (< 50,000 Tons)	0.8430 (Population) – 0.1602 (Per Capita Income)	13	0.7963
1st Order Outliers (>50,000 Tons)	1193 (Industry Employment) – 3.656 (Population) + 13.70 (Total Employment) – 146.6 (Population Density) – 175.2 (Motor Freight and Warehouse Employment) – 139.6 (Air Transportation Employment) + 472.4 (Transportation Services Employment)	21	0.9987
Overall Adjusted R^2 = 0.9181			