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RESEARCH REPORT

AN INTEGRATED FRAMEWORK FOR MODELING FREIGHT MODE AND ROUTE CHOICE

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16. Abstract

A number of statewide travel demand models have included freight as a separate component in analysis. Unlike passenger travel, freight has not gained equivalent attention because of lack of data and difficulties in modeling. In the current state of practice the most commonly used data for freight modeling is the Freight Analysis Framework (FAF) which is a summarized version of the Commodity Flow Survey. FAF data provides commodity flows between zones for seven freight modes. Since a large percentage of goods are carried by trucks, statewide models use FAF data to obtain flows between zones. In other words, the distribution of flow contains a fixed share of mode in a given analysis year. However, for some types of policy analysis this type of assumption might not hold true. For example, the opening of the Panama Canal might change the freight mode choice for certain commodities.

This research presents a methodology to determine freight mode choice to use in the statewide travel demand modeling. By using logistic regression, and commodity-specific From, To, and Within MD models were developed. Examples of each model are discussed in the report. Application of the proposed methodology could potentially be used in the Maryland Statewide Transportation Model (MSTM) was presented. The research results can be used to determine mode choice and to make broad level policy decisions on statewide freight travel.

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EXECUTIVE SUMMARY

In an increasingly competitive national and global economy, shippers, carriers, and other business / industry stakeholders rely on safe, efficient, reliable, and cost-effective freight transportation systems. As a result, there is a growing awareness of the importance of freight transportation and a corresponding thrust at federal, state, metropolitan, and local level. Currently available Metropolitan Planning Organization (MPO) models, due to their scale, have limited capability to address long distance and statewide freight movements. Freight mode and route choice at the MPO level has been largely unfocused because local freight transportation is nearly always by truck and decisions on what mode to use are made external to the MPO region. But at state level the need for a freight model is critical to achieve macro and micro level policy decision-making objectives, such as project planning, corridor studies, and freight tolling. Freight mode choice is a critical part in determining how the choice of mode and route will be determined. The critical factors such as the time value of money by type of commodity movement, attractiveness of a rail mode for long distance freight trips, sensitivity of a freight trip to tolls can be better analyzed with a freight mode and route choice model which operates at a larger scale than MPO models.

The current available data sources such as Freight Analysis Framework (FAF) provide the modal distributions by 128 zones across the country. But for policy analysis and forecasting purposes there is no way one can alter these freight mode shares, as they are fixed over time. This research is aimed at developing freight mode choice models for use in statewide freight travel demand modeling. The scope of research was to use only freely available data sources to inform decision making and provide set of recommendations to the planning agencies about what can be achieved with open source data bases. The research project was also aimed at providing future step recommendations for detailed analysis, if more data needs to be collected. A market share analysis is adapted with critical factors such as the zonal facilities, attractiveness of a rail mode for long distance freight trips, and sensitivity of a freight trip to distance. The probability of choosing a particular mode is the outcome from the type of commodity being carried and a number of network characteristics. FAF data is used to analyze existing shipments, and a logit model is proposed consisting of seven freight modes and a number of FAF data derived independent variables. A nationwide highway and rail network, land use data, toll values and other travel demand data is collected and used in the proposed research. Because of limited data for some modes such as water, pipeline etc., it was not possible to develop mode choice models for these modes. A set of example problems were used in the project to demonstrate the application of the proposed model.

The model is applied in the state of Maryland and the results show that the proposed methodology can be used for higher level policy decision making objectives, such as project planning, corridor studies, and freight tolling. Maryland is facing the potential possibility of an increase in freight demand because of the Panama Canal expansion, opening of Northwest Passage, construction of freight corridors and the addition of new freight rail tracks. The methodology developed in this project can serve as a tool to answer such policy questions.

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CHAPTER 1: INTRODUCTION

Freight transportation is recognized as a subject of increasing interest in transportation planning. The nation's freight transportation system, all modes combined, carried 15.8 billion tons of raw materials and finished goods in 2002, which represented 4,506 billion ton-miles with a value of $10,460 billion (in 2000 dollars). In terms of modes used, trucks play a dominant role. Trucking moved the majority of freight by tonnage and by shipment value: 9.2 billon tons (58% of the total tonnage) and $6,660 billion (64% of the total value) at the national level (BTS, 2005). In large cities, trucks account for around 80% of commodity tonnage moved and around 10% of the vehicle miles traveled (Outwater et al., 2005). Meanwhile, the demands on the freight system are rapidly growing. As an indication, it suffices to say that ton-miles have grown 24% since 1993, while value rose 45% (BTS, 2005). More importantly, higher growth rates have been forecasted in the future (Metro, 2004).

Freight contributes a significant measure of economic performance. Freight-intensive industries for the state of Maryland are expected to grow by 120 percent statewide between 2000 and 2030 (MD Statewide Freight Plan 2009). As a result of this statewide growth, and the corresponding growth across the country, the tonnage of freight transported into, out of, within, and through Maryland is estimated to increase by about 105 percent by 2035, comprising about 1.4 billion total tons and $4.98 trillion of value (an increase of 108 percent over 2006 value). Figure 1-1 shows freight growth by truck and rail between years 2006 and 2030.

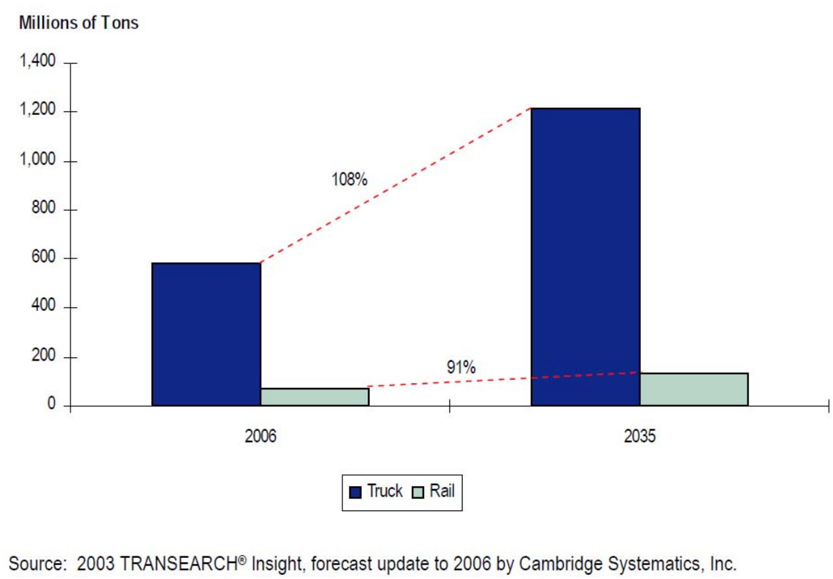


Figure 1-1: Growth in Freight Flow Tonnage by Mode

From a corridor perspective, the largest concentration of freight intensive industries and freight flows will remain on the I-95 corridor, but freight industries and the resulting goods movement on the I-70/I-270 corridor are projected to grow at a faster rate (Figure 1-2).

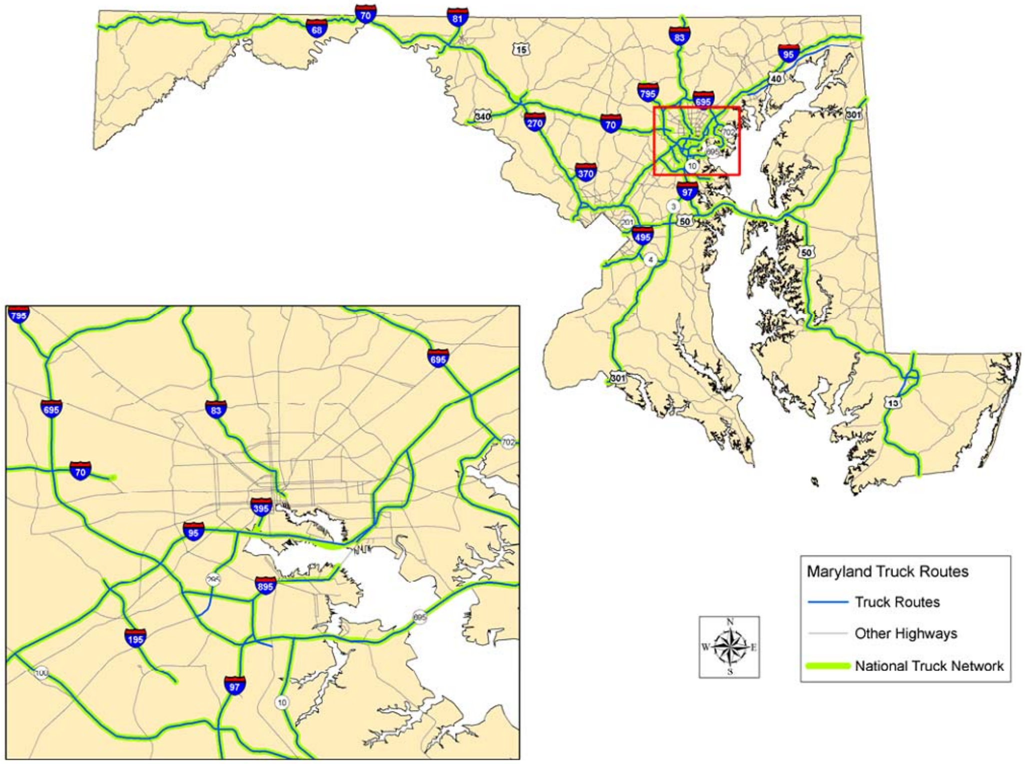


Figure 1-2: Truck Routing System in Maryland (Source: Maryland National System of Highways, Maryland Motor Carrier Handbook 2007)

Currently, the negative externalities produced by freight transportation, such as congestion, accidents, and pollution is being hotly debated. The combination of the positive and negative sides of freight provides potent reasons to develop new methods to evaluate and improve the efficiency of freight transportation systems.

1.1 Modeling Freight

The current travel demand forecasting models are mostly passenger transportation oriented and are insufficient to estimate freight demand and mode split. The statewide models also seldom have the freight module to estimate the freight traffic in detail. The major approach is approximation based on historical trend and pattern. In a long range transportation plan, it is necessary to understand the freight demand, shipper's behavior and route choice decisions to capture the need of future system capacity and multimodal infrastructure. More complex than passenger transportation, freight movement requires coordination among private sector (shippers and carriers), local government, policymakers and other stakeholders. The freight trend becomes a growing concern of public and private decision makers when analyzing policy and investment alternatives.

Currently MPO models, due to their scale, have limited capability to address long distance and statewide freight movements. For example, the effect of a truck traveling west from Baltimore on I-70 then South on I-81 in order to avoid congestion on the DC beltway and I-66 is difficult to analyze using MPO models. Freight mode and route choice at the MPO level has been largely irrelevant because local freight transportation is nearly always by truck and decisions on what mode to use are made external to the MPO region. At the state level, however, the need for a freight model is critical to achieve macro and micro level policy decision making objectives, such as project planning, corridor studies, and freight tolling. Freight mode and route choice is a critical part in determining how the choice of mode and route will be determined. The critical factors such as the time value of money by type of commodity movement, attractiveness of a rail mode for long distance freight trips, and the sensitivity of a freight trip to tolls can be better analyzed with a freight mode and route choice model which operates at a larger scale than MPO models. The objective of this research is to analyze the mode split of freight movements in the state of Maryland. The pattern for mode split according to the commodity type, production and attraction zones are studied. In the next section, a literature review is presented.

The Maryland Statewide Transportation Model (MSTM) also provides a similar picture of highly used truck corridors. Figure 1-3 shows highly travelled truck corridors. Among others, it is evident that I-95, I-270, I-70, I-495 and US 50 are heavily travelled by trucks. Total freight volume will increase, especially on key corridors, as shown in other studies (Maryland National System of Highways, Maryland Motor Carrier Handbook 2007). The State will also need to prepare for the expected growth of East Coast ports, spurred by the Panama Canal expansion, congestion at West Coast ports, rising cost of diesel fuel, and other drivers. To address these issues, the State will have to work closely with industry and neighboring states to make strategic investments. Recognizing the link between the efficiency of the statewide freight transportation system and the continued economic competitiveness of the State, the Maryland Department of Transportation (MDOT) and its partners have developed this comprehensive freight plan to confront these challenges.

Figure 1-3: Heavily travelled truck corridors. (Source: MSTM 2012)

CHAPTER 2: LITERATURE REVIEW

The literature review below provides a thorough review on methods and practices of freight mode choice. There are a number of different ways in which freight modes can be classified. Data source availability is very important for freight mode choice, which is summarized first. Then the factors and the current models for freight mode choice are discussed.

2.1 Data Sources

Prozzi et al. (2006) provided an extensive literature review on currently available commodity related databases in U.S. These datasets, some publicly available and others proprietary, cover from public to commercial, shipment to transport –based. Among them, the most used data sources are the Commodity Flow Survey (CFS), the TRANSEARCH, and the Freight Analysis Framework (FAF). These data sources are discussed in detail below.

Commodity Flow Survey (CFS). Shipment data captured from manufacturing, mining, wholesale, and selected retail and service. The shipment data include distance distributed and origin - destination flows (interstate and intrastate by National Transportation Analysis Regions) by commodity type, mode, shipment size, and value. The CFS was conducted in 1993, 1997, 2002, and 2007.

Transearch. Multimodal freight flow database displays commodity tonnage and loads by mode and between origins and destinations at the county, business economic area (BEA), metropolitan area, and state or provincial levels. The modes included are for-hire truckload, for-hire less-than-truckload, private truck, rail carload, rail/truck intermodal, air, and water. The database is fused from various commercial, public, and proprietary freight data sources, including data from trucking companies shared as part of a Motor Carrier Data Exchange program.

Freight Analysis Framework (FAF). Freight movement among states and major metropolitan areas by all modes of transportation integrated from CFS and additional sources, including estimates for tonnage, value, and domestic ton-miles by region of origin and destination, commodity type, and mode for 2007, the most recent year, and forecasts through 2040.

The CFS and FAF are the target data sources for this research, because they are open to public. The limitation is that the shipments are aggregated to commodity flow among States and MSAs.

2.2 Models for Mode Choice

2.2.1 Mode Choice Factors

Freight movement is a very complicated process. To have a better understanding of mode choice decision-making, it is useful to know the factors that affect freight mode choice and where each factor comes into play during the decision- making process.

CUTR (2002) performed a literature review of available reports and studies covering rail and road freight mode choice, mode shift, and logistics. The review provided a comprehensive list of the key factors that affect freight mode choice at the shipment level and where each factor comes into play during the decision making process. The factors that are important include freight demand characteristics, cross elasticities, freight costs, commodity characteristics, modal characteristics and customer characteristics. Consistently, it is found that trucks dominate short trip lengths and higher value goods, while rail dominates long trip lengths with bulky, low-value products. When the time constraints/service guarantees exit, it is typical that truck is the preferred mode due to speed, flexibility, and reliability.

Cullinane and Toy (2000) applied content analysis to the freight mode/route choice literature. Content analysis is a set of research tools for the scientific study of written documents with the goal of determining ideas and themes contained within them. By summarizing a total of 75 publications, they found that cost, time and characteristics of the goods are the top three factors that affect mode/route choice decision. The results also provided a formal approach to the identification and justification of the attribute used within Stated Preference (SP) experiments.

Nam (1997) performed a survey based on 19 commodity groups with the variables of shipper weight, freight charge, commodity type, origin and destination pair, distance, and daily service frequency, in conjunction with the average form of transit time and accessibility. The elasticity of rate variable is low for both rail and truck modes across six commodity types, though the rail users of two commodity types (paper and basic metal) were demonstrated as quite sensitive to the rate variable. In addition, truck users are more sensitive than rail users in terms of change in the accessibility variable. Transit time was found to have the strongest influence, more for rail and less for road, across all six commodities in this study. However service frequency was rather inelastic for both modes and different commodities.

2.2.2 Model types

The current study on freight mode choice is mostly based on the revealed preference (RP) or stated preference (SP) data from the survey for the shipments, according to the distance, transit time, cost, and other related factors. Logit model are the most commonly used for different categorized mode alternatives, including binary logit, multinomial logit (MNL), nested logit and Mixed MNL. Other models, such as linear regression, ordinal least square estimation (OLS) are also feasible approaches for the mode choice problem.

Jiang, Johnson, and Calzada (1999) used a large-scale, national, disaggregate revealed preference database for shippers in France in 1998 to test mode choice of private or public transportation (rail, road, or combined). The results show that shipping distance, the shipper's accessibility to transportation infrastructure, the shipper's own transportation facilities, and shipment packaging are the critical determinants of the demand for rail and combined transportation.

Samimi, Kawamura, and Mohammadian (2011) collect data from a nationwide establishment survey to test and explain how truck and rail were chosen by the shippers, third party logistics (3PLs), or receivers. The study utilized the binary logit and probit models and focused on both mode-specific variables: transportation cost, haul-time, and access to truck-rail intermodal facilities, and shipment-specific variables: distance, weight, perishability and value of commodity. In addition, decision making unit, past experience, and the use of distribution or consolidation centers are proved to be significant on the modal choice. Shippers, who have been selecting the same mode for two years, are less likely to switch to rail. The authors also tested the sensitivity of freight mode choice changes with fluctuations in fuel cost. The results show that rail shipments are more sensitive to the shipping cost, while road shipments are more responsive to the haul time. The results also suggest that freight mode choice is very much inelastic to the fuel cost.

2.3 Closing Remarks

In this section, literature relevant to the state of the art of freight mode choice studies was summarized. The modeling efforts were related to the available data sources, mode choice factors, and model approaches. Mostly, research was conducted based on the disaggregate survey data from the private sector. Overall, very little contribution was made to explore the aggregate data, which is a major challenge in this research.

CHAPTER 3: DATA

3.1 Data Sources

3.1.1 Freight analysis framework (FAF)

Freight analysis framework (FAF) is the main source of data for this study, as it contains all major resources of freight data similar to commodity flow survey (CFS). FAF^3 (version three) provides the existing commodity movement for the most recent year (2007) as well as forecasts through 2040 based on the four factors of origin, destination, commodity, and mode types. Version 3.2 was released on Dec. 1^{st} 2011 and includes the most recent updates. The state level database of FAF3.2 has been used to develop a freight mode choice for regional freight movement in this stage. In this database, value and weight of shipments from 123 domestic zones and 8 international zones have been tabulated based on 43 individual types of commodity regarding the commodity specifications. The information is tabulated in a way to address the total value and weight of shipment transported annually in terms of 43 commodity types, 131 origin zones, 131 destination zones, and 7 modes.

3.1.2 National Transportation Atlas Database (NTAD)

National Transportation Atlas Database 2011 is a set of nationwide geographic databases of transportation facilities, transportation networks, and associated infrastructure. National highway network, railway network and intermodal terminals are the attribute factors used to represent the features for the FAF zone.

3.1.3 Longitudinal Employer-Household Dynamics (LEHD)

LEHD is a partially synthetic dataset that describes geographic patterns of jobs by their employment locations and residential locations as well as the connections between the two locations. The original data uses census blocks as the base geography. Workplace Area Characteristics (WAC) data by work census block is utilized in this study.

3.2 Variables

In order to better understand the data, variables were constructed to provide a clearer description of freight flows.

3.2.1 Response Variables

The mode split/market share is a set of percentage values with summation equal to one. A binary logistic model is suitable for modeling such a variable with percentage of tonnage by truck, and percentage of tonnage by others as the response. More detailed category of the mode split is not available, because the percentage of tonnage by modes other than truck and rail are too small, which causes problems in model estimation. This study should be implemented to statewide freight model, which uses commodity weight as the input and convert it to trips by payload factors.

3.2.2 Explanatory Variables

3.2.2.1 Distance

Highway distance between origin and destination for truck travel is computed in TransCAD (Caliper, 2012). The FAF zones are added as a layer to the nationwide highway network, and centroid connectors are created with a buffer of 15 miles. The shortest path algorithm is used to compute the distances between zones. A similar approach is adapted to compute the rail O-D distance.

Based on the origin and destination zone, the distance by truck and rail is presented in the OD matrix in

Table **A-1** (in Appendix A) and the corresponding zone is in Table A-2. There is no distance information from or to Alaska (zone 4), and Hawaii (zone 29 and 30). By checking the mode in these zones, no truck and rail is used for Hawaii and no rail used for Alaska. It is assumed that the distance by rail and highway from Hawaii is infinite (equal to 9999999999). The highway distance between Alaska and Maryland is approximated as 4500 miles for three MD zones and rail distance is assumed to be 9999999999. For the within Maryland shipments, the distances within the same FAF region (such as zone 48 to zone 48) are assumed to be 10 miles.

3.2.2.2 Highway and railway coverage

The spatial information for the highway and railway network is aggregated to the FAF zone level in ArcGIS. For the highway network, total mileages of principal arterials and others by urban and rural area are obtained. Railway mileage is measured without differentiating of freight or passenger railway. The variables can be formed in several ways: the exact mileage value, the percentage of principal arterials out of the highway network, or ratios of highway network to railway network, etc. The description of the data is included in Table A-3. Total mileages of railway, principal arterials (PA) and other highways are displayed. The zone ID matches with Table A-2. It is observed that MSA/CSAs are more likely to hold longer PA mileage than other highway network and railway networks. The remaining zones in a State removing the MSA/CSAs have more or similar highway network coverage other than the PA. The values in the table represent how much the shipment in the zone can depend on the type of network facilities.

3.2.2.3 Intermodal facility

The GIS location for the terminals is added to the FAF zone map. Terminals are categorized as truck, rail, port and other according to their major mode type. For example, the mode type of truck-port is categorized as port. Among the rail-truck terminals, 91.5% are in the group of rail and only 8.5% are defined as truck. The facility related variables include the number of each type of terminals in a zone, or percentage of each type of terminals out of the total. The description of the data is included in Table A-4.

3.2.2.4 Transportation related employment

Employment is an important indicator for commodity flow and freight movement. As the study focuses on aggregate mode split by OD zones, the number of transportation employment from the workplace census block was extracted and aggregated to 123 FAF zones. Number of transportation employment and percentage of transportation employment are examined as the explanatory variables. The data is displayed in Table A-5.

3.3 Data Analysis

Narrowing down the scope of work to the State of Maryland, any data with either an origin or destination, or both, inside the state were kept for the analysis and the rest of the data which addressed a shipping movement outside the region were eliminated. The transportation mode for both domestic and international shipments in the original database is categorized into seven various modes: truck, rail, water, air (plus air-truck), multiple modes and mail, pipeline, and other. However, water and pipeline modes are aggregated to the “other” mode because of their negligible percentages, resulting in five major modes. Trade type information which shows that whether the commodity is a domestic product or an import/export one is included in the dataset. Table 3-1 provides the current share of five major transportation mode by weight based on the 42,096 records of data in the FAF database. Table 3-2 shows these percentages in terms of value respectively transported by each mode in 2007. By comparing Table 3-1, Table 3-2 and Figure 3-1, one could tell the mode distribution varies among "within MD", "from MD", "to MD" and the "total". Truck carries most of the weight in "within MD" and "from MD" (around 90%), while only 60% in to MD shipments. Then we compare count, weight and value mode splits within the OD (within, from and to). Truck carries the most weight and values of the shipment (over 90%) within MD. Air, multiple modes & mail (multimodal) and other counts around 4% by weight, but mostly for light and high unit value commodities (14% by value). The shipment from MD is different in distribution, with 88% truck, 3.3% multimodal and 4% rail. The shipments to MD also use truck as a major choice, which is 61% by weight, but s much higher percentage by rail (22.8%) and multimodal (20.7%). Multimodal shipments from and to MD count more percentage wise than within MD by value.

Comparing the total weight and value carried by each mode, truck carries around 80% of both weight and value. Around 8% of total weight is carried by rail, and only 2.35% of the value. This indicates that the heavy and low unit value commodities are more often shipped by rail comparing with truck. In the contrast, commodities' value are much higher by air and multimodal, with 0.02% and 4.21% of total weight counting 1.07% and 13% in total value, respectively.

Table 3-1: Shipments within, from, and to Maryland by mode (2007); Unit: thousand tons

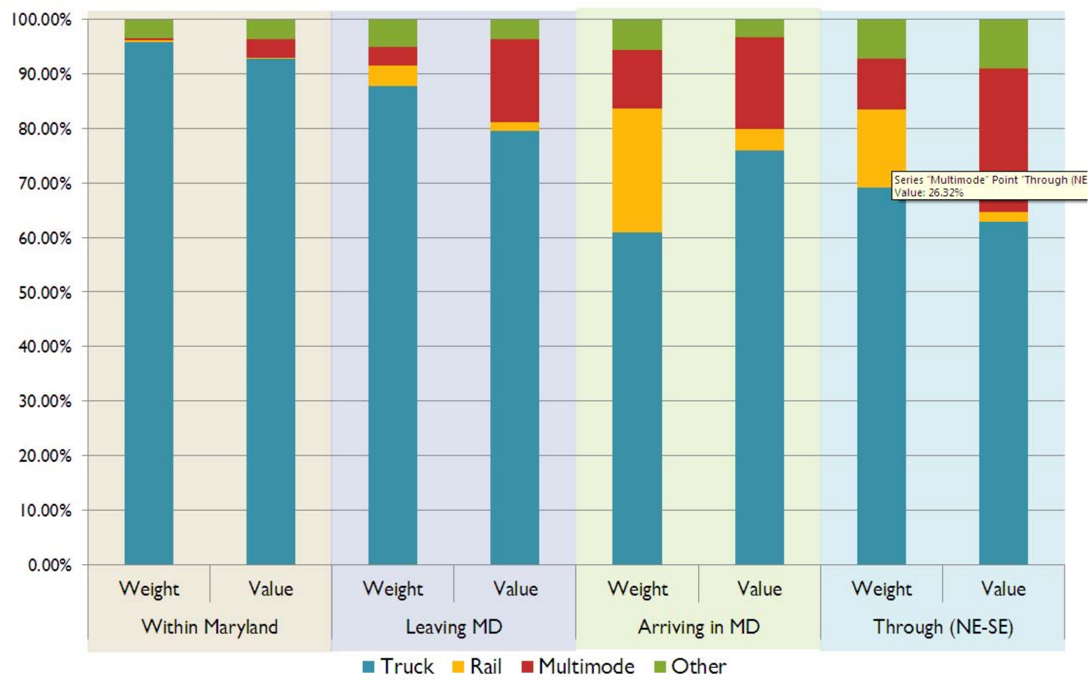
Mode	within		From		To		Total	
	Weight	Percent	Weight	Percent	Weight	Percent	Weight	Percent
Truck	129,411	95.87%	74,067	87.80%	55,711	60.91%	259,189	83.39%
Rail	474	0.35%	3,209	3.80%	20,830	22.78%	24,513	7.89%
Air (include truck-air)	4	0.00%	44	0.05%	22	0.02%	70	0.02%
Multiple mode & mail	490	0.36%	2,786	3.30%	9,799	10.71%	13,075	4.21%
Other	4,612	3.42%	4,249	5.04%	5,098	5.57%	13,959	4.49%
Total	134,990	100%	84,356	100%	91,460	100%	310,806	100%

Consistent with Source: Freight Analysis Framework Version 3.2

Table 3-2: Shipments within, from, and to Maryland by mode (2007); Unit: $million

Mode	within		From		To		Total	
	Value	Percent	Value	Percent	Value	Percent	Value	Percent
Truck	85,115	92.72%	89,602	79.57%	128,642	75.93%	303,359	81.15%
Rail	166	0.18%	1,771	1.57%	6,848	4.04%	8,785	2.35%
Air (include truck-air)	303	0.33%	1,796	1.60%	1,884	1.11%	3983	1.07%
Multiple mode & mail	3,109	3.39%	17,142	15.22%	28,329	16.72%	48,580	13.00%
Other	3,109	3.39%	2,292	2.04%	3,715	2.19%	9,116	2.44%
Total	91,802	100%	112,604	100%	169,417	100%	373,823	100%

Consistent with Source: Freight Analysis Framework Version 3.2



Note: NE-SE represents NE (CT, DE, ME, MA, NH, NJ, NY, RI,VT) -SE (FL, GA, NC, SC)

Figure 3-1: Modal split based on shipment count, weight, and value within, from, and to Maryland (2007)

For Maryland, the major commodities by weight and value are presented in the Table 3-3. It is shown that “other foodstuffs” are in the top list of weight and value for all the three types of ODs. Mixed freight is another major product to and from MD. Generally, the commodities with the higher weight are not among the top ten by value.

For each commodity, the value/weight (thousand$/ton) are different for the three types of OD: to, from and within MD. As Table A-6, the data is within the range of (0.01, 116). Generally, the ratios for the three types of OD are similar. But there are still special cases, such as precision instruments, whose value is over 100,000$/ton for the product shipped from MD, but much less valuable for to and within MD (36,000 and 15,000$/ton).

The following Figure 3-2a is a scatterplot of the truck share (%) by logarithm of the value/weight. The pattern is roughly declining for the blue and red dots, representing that the more valuable commodities are less shipped by truck. The ln(value/weight) of commodities with over 80% truck share ranges from -5 to 4. The ratio of medium truck carried commodities ranges from -3 to 5 roughly. Truck share lower than 40% are mostly valuable with positive ln(value/weight). The declining pattern is not obvious for the commodities within MD.

Table 3-3: Top 10 commodities by weight (million tons) and value ($billion)

	To MD		From MD		Within MD	
weight	Other foodstuffs	10.6	Coal	24.5	Gravel	21.7
	Gravel	9.0	Coal-n.e.c.	7.6	Waste/scrap	20.9
	Nonmetal min. prods.	8.2	Gravel	6.8	Nonmetal min. prods.	15.3
	Coal-n.e.c.	6.0	Other foodstuffs	4.5	Coal-n.e.c.	11.8
	Basic chemicals	5.5	Mixed freight	3.6	Natural sands	8.9
	Waste/scrap	4.7	Wood prods.	3.5	Nonmetallic minerals	7.9
	Base metals	4.2	Nonmetal min. prods.	3.1	Other foodstuffs	4.5
	Wood prods.	3.5	Base metals	2.9	Gasoline	4.2
	Cereal grains	3.2	Natural sands	2.6	Metallic ores	3.8
	Mixed freight	3.1	Fuel oils	2.4	Fuel oils	3.7
value	Mixed freight	12.6	Pharmaceuticals	32.5	Machinery	18.5
	Machinery	10.9	Electronics	21.2	Mixed freight	7.1
	Electronics	10.0	Motorized vehicles	13.8	Pharmaceuticals	6.0
	Pharmaceuticals	9.6	Mixed freight	13.0	Motorized vehicles	5.2
	Motorized vehicles	9.3	Machinery	10.4	Other foodstuffs	4.6
	Other foodstuffs	6.4	Textiles/leather	8.6	Coal-n.e.c.	4.3
	Textiles/leather	4.9	Misc. mfg. prods.	6.4	Electronics	3.8
	Base metals	4.4	Plastics/rubber	5.3	Unknown	3.8
	Chemical prods.	4.3	Other foodstuffs	5.3	Articles-base metal	3.7
	Misc. mfg. prods.	3.7	Chemical prods.	5.0	Textiles/leather	2.9

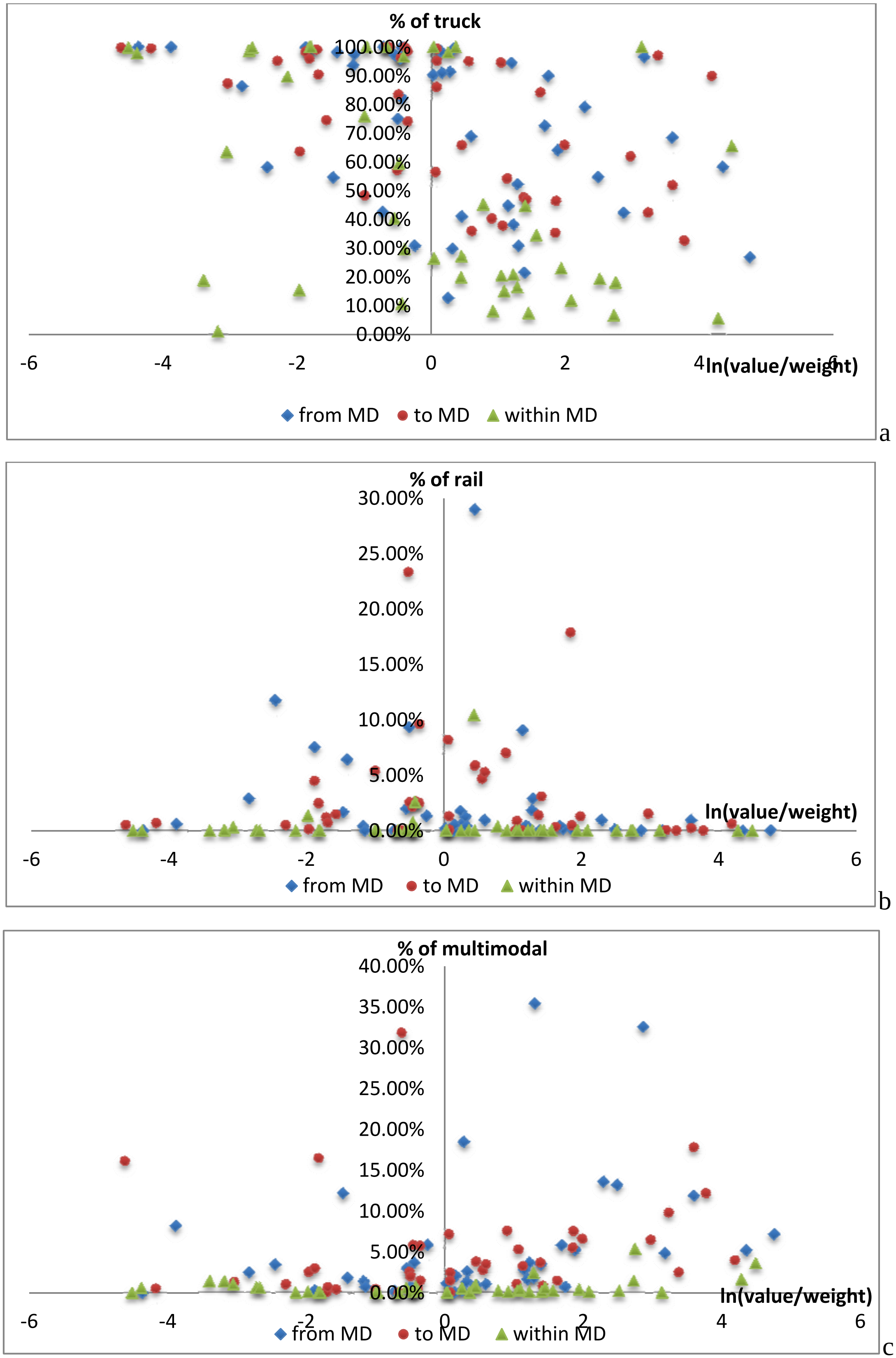


Figure 3-2: Scatterplot of the mode share (%) by logarithm of the value/weight

In the Figure 3-2b of percentage of rail across ln(value/weight), we observe that the rail mode is more frequently selected by the commodities with the x-value within (-2, 2), means value/weight neither too high nor too low. The Figure 3-2c indicates that more percentage of the commodities with higher unit value is shipped by multimodal, as the increasing trend in the plot.

From the above discussion, the commodities are categorized according to their truck share. In the Figure A-1, the truck percentage by tonnage for from (a), to (b), and within (c) MD by each commodity is plotted in order from low to high. The pattern for (a), (b), (c) are different but we could classify the commodities into 3 groups shown in Figure A-1, as: (1) low truck percentage, (2) medium truck percentage, (3) high truck percentage. The groups of the commodities for from and to MD are marked in the following Table 3-4. For example, live animals/fish is in group 3 (high truck percentage) for both from and to MD categories, and Basic chemicals (#20) is in group 1 (low truck percentage) of the shipments from MD but in group 2 (medium truck percentage) for shipments to MD. The shipments within MD are not further studied in this project because the shipment within MD is unique and the FAF data for three zones of MD are not enough to support a reasonable model.

Table 3-4: The classification of the commodities

		From	To			From	To			From	To
1	Live animals fish	3	3	**15**	Coal	3	3	**29**	Printed prods	1	1
2	Cereal grains	3	3	**16**	Crude petroleum	3	3	**30**	Textiles leather	2	2
3	Other ag prods	3	3	**17**	Gasoline	3	3	**31**	Nonmetal min. prods	2	3
4	Animal feed	3	3	**18**	Fuel oils	3	3	**32**	Base metals	2	2
5	Meat seafood	3	3	**19**	Coal-n.e.c.	2	2	**33**	Articles-base metal	1	2
6	Milled grain prods	3	3	**20**	Basic chemicals	1	2	**34**	Machinery	2	2
7	Other foodstuffs	3	3	**21**	Pharmaceuticals	2	1	**35**	Electronics	2	2
8	Alcoholic beverages	3	3	**22**	Fertilizers	2	3	**36**	Motorized vehicles	2	1
9	Tobacco prods	3	3	**23**	Chemical prods	1	1	**37**	Transport equip	2	3
10	Building stone	3	3	**24**	Plastics rubber	2	1	**38**	Precision instruments	1	2
11	Natural sands	3	3	**25**	Logs	3	2	**39**	Furniture	3	2
12	Gravel	3	3	**26**	Wood prods	3	2	**40**	Misc. mfg. prods	2	2
13	Nonmetallic minerals	2	2	**27**	Newsprint paper	1	3	**41**	Waste scrap	3	3
14	Metallic ores	1	3	**28**	Paper articles	2	2	**43**	Mixed freight	2	2

CHAPTER 4: PROPOSED MODEL AND RESULTS

A logistic regression model was developed to study the share of commodity weight shipped by truck and rail. The FAF data is aggregated as total Annual shipment by Tonnage (KTon), Value (M$) and Ton-Miles by domestic/foreign origin, destination and mode. Therefore, it is not valid to conduct discrete choice model, such as multinomial logit. Mode share, especially truck share is one of the research concerns. As with high fuel price or expanding rail and port intermodal facilities, the mode share would shift from truck to others, and may alleviate the highway congestion. One of the targets is to investigate the share of truck and its relation to land use planning, such as the location of distribution centers.

Other analysis methods were also explored. For example, in the following Figure 4-1, the ln(number of truck centers/number of rail center) was plotted against the logit(truck%). The correlation pattern is not strong enough.

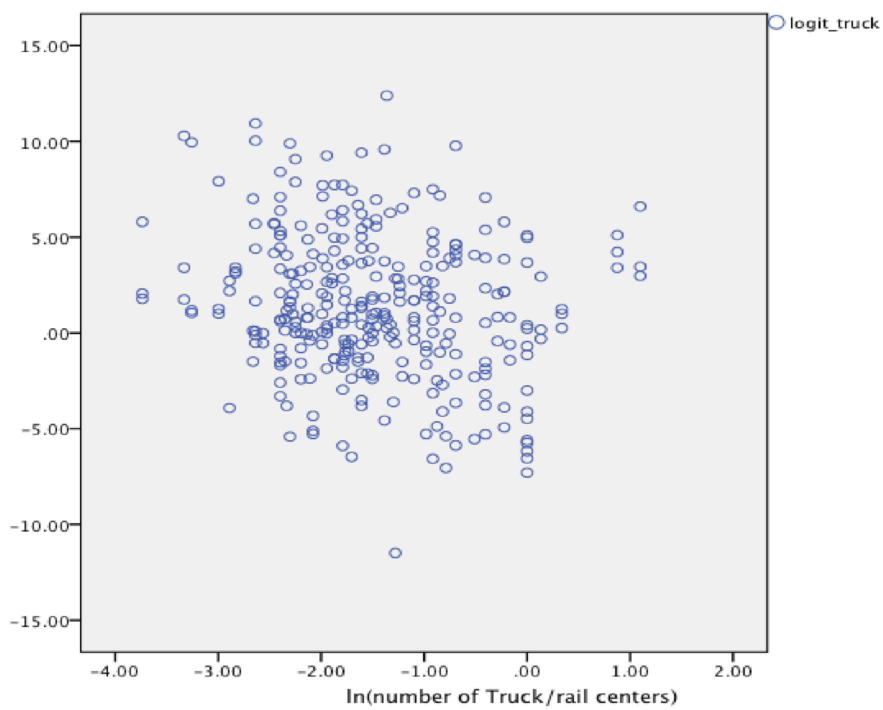


Figure 4-1: Plotting of the logit(truck share percentage) against the ln(number of truck/rail centers)

The distance between the OD is highly correlated with the truck share as shown in the Figure 4-2 below. Linear, polynomial and cubic regression were tested and cubic regression provides the best fit.

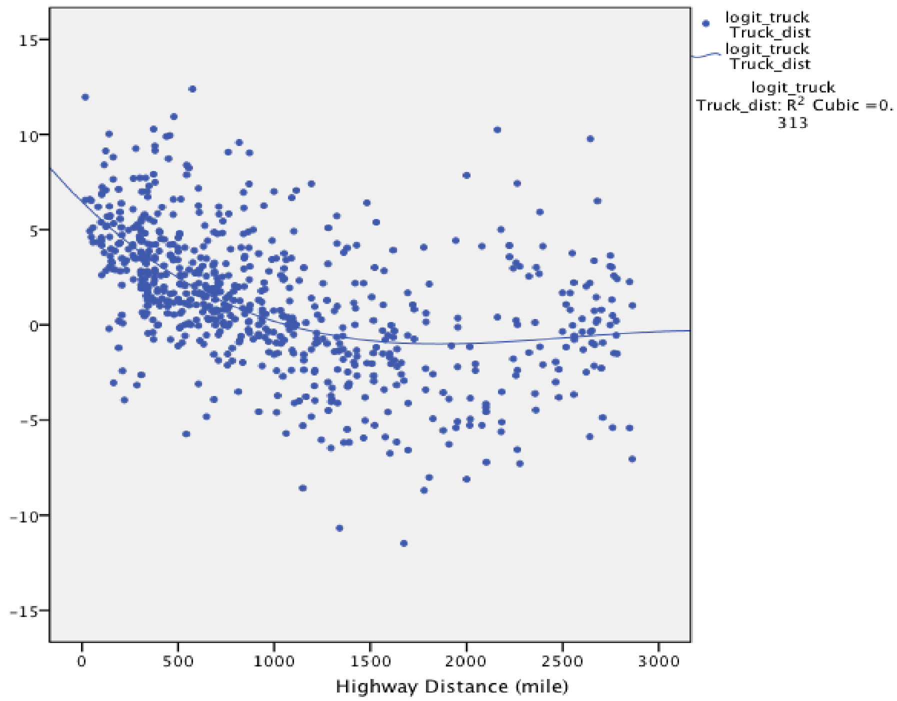


Figure 4-2: Plotting of the logit(truck share percentage) against the highway distance

4.1 Model Formulation

The formulation of the model is a Logistic Regression Model:

$$logit(P_{ij}) = X_{ij}\beta_j + \varepsilon_{ij} \qquad (1)$$

where, P_{ij} is the probability of Truck Tonnage share,

X_{ij} is the characteristics of shipping distance, distribution centers, highway/railway coverage, transportation/warehousing employment.

$$log\left(\frac{P_{ij}}{1-P_{ij}}\right) = X_{ij}\beta_j + \varepsilon_{ij} = \beta_0 + \beta_1 Dist + \beta_2(DC_O) + \beta_3(DC_D) + \beta_4(Cov_O) + \beta_5(Cov_D) + \beta_6(Emp_O) + \beta_7(Emp_D) \ldots + \varepsilon_{ij} \qquad (1)$$

DC_O represents the characteristics of distribution centers in the origin zone, such as number of distribution centers, percentage of truck/rail/port related centers, or truck/rail centers.

Cov_O is the coverage of the highway/railway in the origin zone, e.g., total mileage of the highway arterials/railroad in the zone, or percentage of the principle arterials out of total highways.

Emp_O is the transportation related employments in the origin zone.

DC_D, Cov_D, and Emp_D are the variables describing destination zones.

4.2 Model Result

The modeling result is discussed below for four combinations: from MD low truck share, from MD medium truck share, to MD low truck share, to MD medium truck share. The group 3 commodity is not studied because the truck share is over 80%, and less likely to be shift to other modes.

Table 4-1: Estimation result of group 1 commodity shipped from MD

Parameter		Estimates	95% CI Lower	95% CI Upper	Wald Chi-Square
(Intercept)	X0	.431	-2.580	3.442	.079
Highway distance	X1	-.002	-.003	-.001	19.315
# Origin zone truck center	X2	2.463	.417	4.508	5.569
# Origin zone rail center	X3	-.164	-.272	-.055	8.766
# Destination zone truck center	X4	.414	.108	.720	7.018
# Destination zone rail center	X5	-.024	-.056	.007	2.265
# Destination zone port center	X6	.286	-.075	.647	2.412
# Destination zone Trans employment (10K)	X7	-.133	-.310	.044	2.160

Highway distance is the most significant among all the variables. The negative coefficient -0.002 indicates that the truck is less preferred by the shipment between ODs that are farther. Distribution centers in both origin and destination zones are also significant. Shipments from three FAF zones in MD are more likely to choose truck from the zones with more truck distribution centers and less rail centers. Destination zones with more truck centers and port centers and less rail centers attract more shipments by truck. The distribution centers of the origin and destination zones influence the percentage of the total shipments by truck and also the decision choice by the shippers. If the OD zones have more rail centers, the truck is less preferred, because there are more choices and competition among the carriers. The highway and railway coverage is not significant in the model. Employment in the destination zone has negative effect, implying less truck share with more transportation employees. In other words, the transportation employment increases the rail service more than truck service leading to lesser share for trucks.

Example-1 presented below shows how the probability of truck share changes with various input parameters. Using the parameters shown in Table 4-1, it is found that if total group 1 commodity is shipped from Baltimore to Denver then the probability of using truck as a mode is 62.3%. If there is one more port related distribution center located in Baltimore then the truck percentage does not change because port related distribution center is not a factor in the statistical results shown in Table 4-1. If there is one more truck related center in Baltimore then the probability that commodity 1 will be using truck increases to 95.1%, demonstrating a positive correlation between truck related centers and the probability of using trucks. Similarly, if there is one more rail center in Baltimore then the probability of using truck decreased to 58.3%. This is because of the negative correlation between rail related center and the probability of using trucks.

Example-1:

- *The total group 1 commodity shipped from Baltimore (MD MSA) to Denver (CO CSA)*
  - P_t=62.3%
  - *(Note: distance is shown in Table A-1. Using all the parameters shown in Table 4-1, one can calculate the probability using equation-1.* $log\left(\frac{P_t}{1-P_t}\right) = 0.431 - 0.002(Dist) + 2.463(\#\ Origin\ zone\ truck\ center) - 0.164(\#\ Origin\ zone\ rail\ center) + 0.414(\#Destination\ zone\ truck\ center) - 0.024(\#Destination\ zone\ rail\ center) + 0.286(\#Destination\ zone\ port\ center) - 0.133(Destination\ zone\ transportation\ employment\ in\ 10\ thousands)) + \varepsilon_{ij}$*)*
- *If there is one more port related distribution center in Baltimore*
  - *The truck share does not change.*
- *If there is one more truck center in Baltimore*
  - P_t=95.1%
  - *(Note: use coefficients from Table 1 and equation 1 to estimate probability)*
- *If there is one more rail center in Baltimore*
  - P_t=58.3%
  - *(Note: Note: use coefficients from Table 1 and equation 1 to estimate probability)*

Similarly, a second example is presented when the destination zone is changed from Denver to Jacksonville. The results of example 2 follow a similar pattern as the previous example, but the probability of using truck is higher. This is because of smaller distance from Baltimore to Jacksonville. Results from Table 4-1 suggest that probability of truck percentage increases with reduced distance.

Example-2:

- *If the Destination zone is Jacksonville (FL MSA)*
  - *Distance reduces from 1,591 mi to 756mi.*
  - *Employment reduces from 5.17 to 3.22 10K.*
  - P_t*=91.9%*
- *With one more port-truck distribution center in Baltimore*
  - *The truck share does not change.*
- *If there is one more truck center in Baltimore*
  - P_t*=99.3%*
- *If there is one more rail center in Baltimore*
  - P_t*=90.6%*

For the group 2 commodity shipped from MD, distance is still significantly negative correlated with the truck share. The number of distribution centers in the origin zone (MD) is not significant. The truck share will be less if the destination zone has more rail centers. The more principal arterials out of the total transportation networks in the destination zone will encourage the shippers to choose truck rather than others. This is comparing the coverage of rail networks and highway networks. Higher principal arterials percentages mean relatively less rail networks and more convenience of shipping, transition and distribution. Opposite to the first model, employment has a positive coefficient. More transportation related employees in the destination zone increase the truck share.

Table 4-2: Estimation result of group 2 commodity shipped from MD

Parameter		Estimates	95% CI Lower	95% CI Upper	Wald Chi-Square
(Intercept)	X0	.689	-.542	1.920	1.204
Highway distance	X1	-.002	-.003	-.002	65.168
# Destination zone rail center	X2	-.022	-.044	.000	3.676
Destination zone principal arterial percentage out of total highway and rail mileage	X3	3.660	.822	6.498	6.388
# Destination zone Trans employment (10K)	X4	.112	.013	.210	4.956

Example-3 is used to demonstrate the percentage of truck share for group 2 commodities. Distance is found to be a major factor that determines the probability of truck percentage (negatively correlated). Transportation related employment is also a contributing factor.

Example-3:

- *The total group 2 commodity shipped from Baltimore (MD MSA) to Denver (CO CSA)*
  - P_t=31.6%
- *If the Destination zone is Jacksonville (FL MSA)*
  - *Distance reduces from 1,591 mi to 756mi.*
  - *Employment reduces from 5.17 to 3.22 10K.*
  - *Others are close.*
  - P_t=66.9%
- *If the Destination zone is Austin TX MSA*
  - *Similar distance and highway coverage with Denver*
  - *Less rail centers and low transportation related employment*
  - P_t=29.9%
- *Distance is a major factor influence the truck share of group 2 commodities from MD.*

Then the model is applied to the shipments to MD. For the total commodities in group 1 (low truck percentage), highway distance is still negative correlated, but less significant than the other models. The number of port related distribution centers is negatively correlated with the truck share, indicating shipments to MD are less carried by truck with more port centers in the origin zone. It is because there are more options such as shipping by water for the zones along the coast than the zones inland. The percentage of rail centers out of the total distribution centers in MD has a significantly negative effect. The Baltimore zone has 16 rail centers that count 52%, but remainder of the MD has 3 rail centers that count 60%. Washington DC area has no rail distribution centers. Then the shipments are more likely carried by truck for the DC area. Employment still has positive coefficient in this model.

Table 4-3: Estimation result of group 1 commodity shipped to MD

Parameter		**Estimates**	**95% CI Lower**	**95% CI Upper**	**Wald Chi-Square**
(Intercept)	X0	2.720	2.019	3.421	57.850
Highway distance	X1	-0.001	-0.001	0.000	3.981
# Origin zone port related distribution center	X2	-0.158	-0.373	0.058	2.060
Destination zone rail center percentage	X3	-2.020	-3.246	-0.794	10.431
# Origin zone Trans employment (10K)	X4	0.040	-0.023	0.102	1.565

Example-4 shows that probability of using truck for group 1 commodities largely depends on transportation related employment. Similar to previous models, the truck percentage is likely to decrease with longer distance origins. Three origin zones are used in Example-4 to demonstrate the case.

Example-4:

- *The total group 1 commodity shipped to Baltimore (MD MSA) from Denver (CO CSA)*
  - P_t=68.1%
- *If there is one more rail distribution center in Baltimore area*
  - P_t=67.7%
- *If the Origin zone is Jacksonville (FL MSA)*
  - *Distance reduces from 1,591 mi to 756mi.*
  - *Employment reduces from 5.17 to 3.22 10K.*
  - *Others are close.*
  - P_t=78.0%
  - *Truck is preferred between Origins and Maryland with shorter distance.*
- *If the Origin zone is Austin TX MSA*
  - *Similar distance and #ports related centers with Denver*
  - *Low transportation related employment*
  - P_t=65.7% *less than the truck share from Denver*

The last model is for group 2 commodity shipped to MD. Distance is still significantly negative. The railway coverage out of the total network in the origin zone is negatively related with truck share. If the origin zone is dominated by railway, the shipper would like to choose shipping by rail, not truck. A greater number of transportation employees have positive impact on the truck share.

Table 4-4: Estimation result of group 2 commodity shipped to MD

Parameter		Estimates	95% CI Lower	95% CI Upper	Wald Chi-Square
(Intercept)	X0	3.055	1.351	4.760	12.340
Highway distance	X1	-.002	-.003	-.002	54.749
Origin zone percentage of rail miles out of total highway and rail mileage	X2	-3.576	-7.274	.123	3.590
# Origin zone Trans employment (10K)	X3	.074	.000	.147	3.882

Example-5 shows the probability of using truck for group 2 commodities. Like group 1 commodities, group 2 also depends on origin zone transportation related employment. Two other factors - highway distance and percentage of rail miles out of total are negatively correlated to truck share. Example-5 uses three origin zones to demonstrate that the results.

Example-5:

- *The total group 2 commodity shipped to Baltimore (MD MSA) from Denver (CO CSA) by truck*
  - P_t=23.3%
- *If the Origin zone is Jacksonville (FL MSA)*
  - *Distance reduces from 1,591 mi to 756mi.*
  - *Rail coverage from 0.3 to 0.34*
  - *Employment reduces from 5.17 to 3.22 10K.*
  - P_t=59.6%
- *If the Origin zone is Austin TX MSA*
  - *Similar distance and rail coverage with Denver*
  - *Low transportation related employment (1.1)*
  - P_t=20.4%
- *Distance is a major factor influence the truck share of group 2 commodities to MD.*

Though trucks carry a large portion of goods, some of the other modes do carry smaller percentage. Table 4-5 shows weight by other shipping mode besides pipeline. Beyond the analysis for truck share out of the total shipping tonnage, the rest of the shipping modes are further studied. Removing the shipments by pipeline, there are four other modes as shown in the table: Multi-mode, rail, water and air. Water and air only count for a small percentage by weight in the total.

Table 4-5: Weight by other shipping Modes other than Pipeline

Mode	From MD Group 1		From MD Group 2		To MD Group 1		To MD Group 2	
	Weight (Kton)	%	Weight (Kton)	%	Weight (Kton)	%	Weight (Kton)	%
Multi-mode	54.19	33.91	672.69	31.29	181.23	31.54	1429.07	32.70%
Rail	104.24	65.23	1425.20	66.29	387.34	67.42	2856.76	65.36
Water	0.00	0.00	18.48	0.86	0.00	0.00	77.37	1.77
Air	1.39	0.87%	33.65	1.57%	5.99	1.04%	7.41	0.17

Similar to the model for truck share, similar model was estimated for shipment weight by rail out of the total four modes. The result is displayed in Table 4-6. For group 1 commodity from MD, only the number of port related distribution centers and percentage of principal arterial highways are significant. Changes in FAF zones in MD do not influence the choice between rail and multimodal. For the group 2 commodities from MD, more truck centers in the destination zone discourage the shipments by rail rather than Multi-mode. The estimation for the shipments to MD has similar results. More truck centers in the origin zone decrease the rail share for group 1 commodities, but increase the rail share for group 2 commodities. More rail centers in origin zone increase the share of commodity weight in both situations. The preference for rail declines with more truck centers in MD for all these commodities. Rail is less preferred compared to multi-mode from the zones in MD with more rail distribution centers. Multi-mode, such as rail-truck or rail-air, is more encouraged by more rail centers than shipping by rail only.

Table 4-6: Estimation Results for Commodity Group 1 and 2 for Rail Mode

Group	Parameter	B	95% Wald Confidence Interval		Hypothesis Test
			Lower	Upper	Wald Chi-Square
Group1 Commodity from MD	(Intercept)	5.525	2.933	8.117	17.46
	Highway distance	-0.001	-0.002	0	6.533
	# Destination zone port related distribution center	0.29	-0.002	0.582	3.783
	Destination zone	-12.539	-17.422	-7.655	25.324
Group2 Commodity from MD	(Intercept)	3.822	-0.862	8.506	2.557
	Highway distance	-0.002	-0.003	-0.001	23.284
	# Destination zone truck center	-0.228	-0.381	-0.075	8.536
	Destination zone truck center percentage	-14.252	-20.424	-8.08	20.486
Group1 Commodity to MD	(Intercept)	-2.339	-4.357	-0.32	5.158
	Highway distance	-0.001	-0.002	0	6.233
	# Origin zone truck center	-0.276	-0.461	-0.091	8.558
	# Origin zone rail center	0.155	0.101	0.209	31.586
	Destination zone truck center percentage	-6.958	-12.129	-1.787	6.954
Group2 Commodity to MD	(Intercept)	7.195	4.799	9.592	34.62
	Highway distance	0	-0.001	-6.50E-05	5.541
	# Origin zone truck center	0.127	0.008	0.246	4.349
	# Origin zone rail center	0.044	0.019	0.069	11.756
	Destination zone truck center percentage	-2.173	-3.488	-0.858	10.495
	Destination zone rail center percentage	-5.759	-8.147	-3.372	22.361
	Origin zone principal arterial percentage out of total highway and rail mileage	-8.946	-12.704	-5.188	21.774

In summary, the model estimation results are:

- For Group 1 commodities, the number of truck and rail centers will influence the percentage of tonnage carried by truck.
- For Group 2 commodities, the percentage of truck tonnage only depends on the characteristics of the opposite zones (destination zone for From MD model and origin zone for To MD model).
- The distance is a dominant variable related to truck share.
- The principal arterial highway and rail coverage in the opposite zones are related to truck share for group 2, but not group 1.
- The number of transportation/warehousing employments in the opposite zones is significant.
- Variables such as highway and rail coverage in MD and employment in MD are not significant.

4.3 Result Application

One of the critical components of this research was to provide insights to improve the freight mode choice component of the MSTM. Currently MSTM uses FAF data to distribute trips between zones and uses trip assignment for routing freight traffic (Figure 4-3). First, the FAF[3] data are disaggregated to counties across the entire U.S. by eleven employment types in each county. Within the MSTM region, detailed employment categories are used to further disaggregate to Statewide Modeling Zones (SMZ). Finally, commodity flows in tons are converted into truck trips using average payload factors.

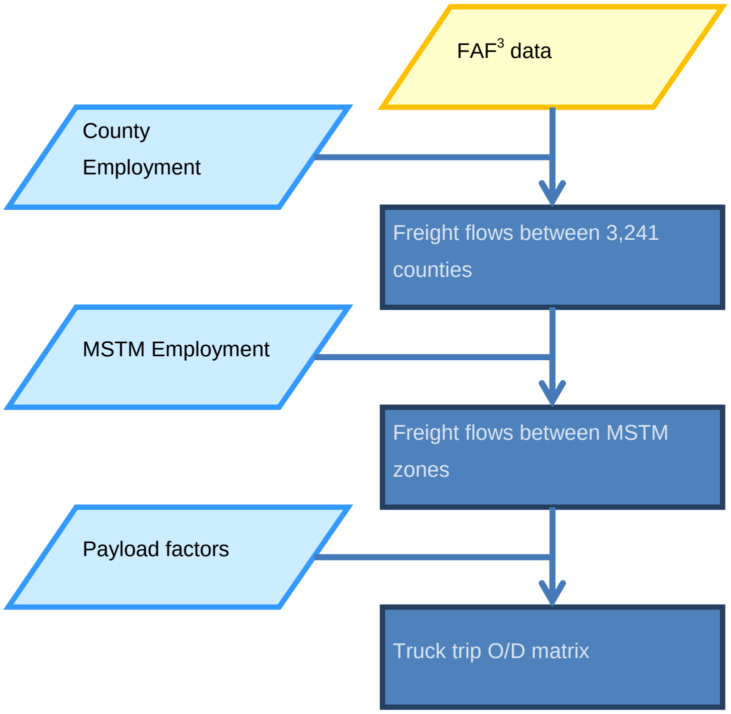


Figure 4-3: Methodology for Regional Truck Model in MSTM (Source MSTM 2013)

A revised methodology is shown in Figure 4-4. Since, FAF provides fixed mode shares and not suitable for policy decision making, the proposed mode choice model developed in this project can be used for determining shares for each mode between origin destination pairs (as shown in dotted box of Figure 4-4). The fitness of the model is not proved to be good enough for prediction the mode shares of water, pipeline, etc. because of the small sample sizes. The model result can be applied to estimate the truck share approximately. A sensitivity test is presented below to examine the application of the model in MSTM.

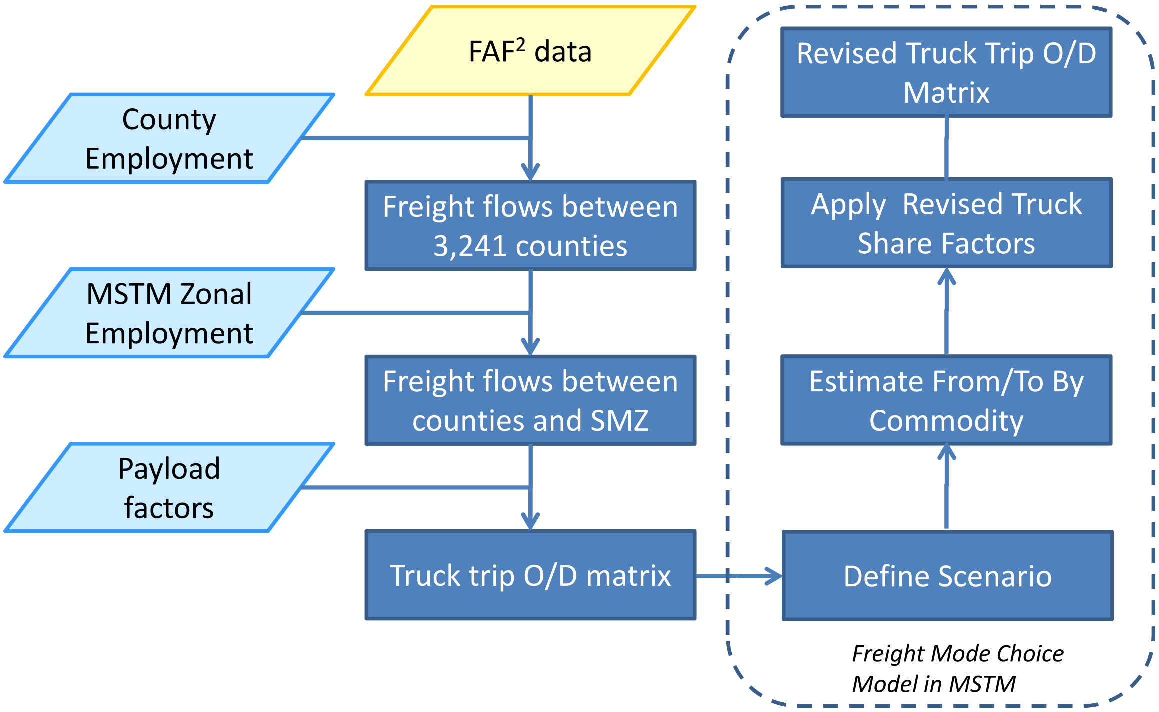


Figure 4-4: Integration of Proposed Model in MSTM for Freight Mode Choice

For example, for commodities in group 1, the predicted average truck share is 0.76, 0.78 and 0.92 for zone 48 (Baltimore), 49 (Washington MD part) and 50 (remainder of MD). With one more truck center in the destination zone, the truck share increases to 0.80, 0.82 and 0.94. That is relatively 2.13%, 4.98% and 5.45% increase in the truck share, respectively. Then the current OD matrix of total tonnage used as the input to the MSTM can be modified accordingly based on the changes of the OD land use factors.

The sensitivity is summarized in Table 4-7. The value in the table means the ratio changes in the average zonal truck share with 1 more increase in the number or 1% increase for the percentage for each parameter. For example, 1.2314 means the truck share is 1.2314 times the current truck share with 1 more truck center in the origin zone (MD). If the total tonnage is $W_{48,i}$ between from zone 48 to zone i, the current value of the cell in the input matrix to MSTM is $T_{48,i}$. The new cell should be $1.2314T_{48,i}$. If the truck share is 0.9763 of the current value, the cell is $0.9763T_{48,i}$

Table 4-7: Result of average ratio changes

	Parameter		Zone 48	Zone 49	Zone 50
Group 1 from MD	# Origin zone truck center	X2	1.2314	1.209	1.0761
	# Origin zone rail center	X3	0.9763	0.9783	0.9904
	# Destination zone truck center	X4	1.0545	1.0498	1.0213
	# Destination zone rail center	X5	0.9966	0.9969	0.9986
	# Destination zone port center	X6	1.0384	1.0351	1.0152
	# Destination zone Trans employment (10K)	X7	0.9809	0.9825	0.9923
Group 2 from MD	# Destination zone rail center	X2	0.9930	0.9931	0.9928
	Destination zone principal arterial percentage out of total highway and rail mileage (1%)	X3	1.0115	1.0114	1.0120
	# Destination zone Trans employment (10K)	X4	1.0352	1.0349	1.0366
Group 1 to MD	# Origin zone port related distribution center	X2	0.9474	0.9713	0.9413
	Destination zone rail center percentage (1%)	X3	0.9934	0.9964	0.9926
	# Origin zone Trans employment (10K)	X4	1.0131	1.0069	1.0147
Group 2 to MD	Origin zone percentage of rail miles out of total highway and rail mileage (1%)	X2	0.9883	0.9883	0.9878
	# Origin zone Trans employment (10K)	X3	1.0242	1.0240	1.0252

4.4 Recommendations for Future Research

Developing a comprehensive model to inform decision making through understanding of the mode-choice factors from a shipper's perspective will be helpful. With the availability of detailed data, a discrete choice model can be developed. A detailed survey is proposed by Florida Department of Transportation to determine factors related to freight mode choice, and are presented in Table 4-8. Information on the physical attributes of goods shipped, why the existing mode was chosen, what options currently exist for movement of goods, and what plans if any exist for goods movement in the future will be helpful for model development. The timing of factors on decision making such as (1) immediate, (2) mid-term, and (3) final is also suggested in Table 4-8. Survey questions encompassing various commodity types should be identified for potential survey respondents, including agricultural firms, metals and metal manufacturing firms, paper manufacturers, lumber firms, chemicals and transportation firms (Table 4-9). Examples of survey methods include:

1. Roadside Surveys
2. Combined Telephone/Mail-Back Surveys
3. Telephone Interview Surveys
4. Mail-out/Mail-back Surveys
5. Personal Interview Surveys
6. Internet Surveys
7. Focus and Stakeholder Group Surveys
8. Commercial Vehicle Trip Diary Surveys
9. Global Positioning System Vehicle Tracking Surveys
10. License Plate Match Surveys—Manual and Electronic

Table 4-8: Mode Choice Factors and Timing in Decision Making (Source: FDOT 2002)

Factor 1	Factor 2	Immediate			Mid-Term		Final			
		1	2	3	4	5	6	7	8	9
Total logistics cost	Transportation charges	■								
	Capital carrying cost in transit		■							
	Service reliability costs		■							
Modal characteristics	Trip time and reliability		■							
Physical attributes of goods	Shipment size			■						
	Package characteristics			■						
	Shipment shelf life			■						
	Shipment value			■						
	Shipment density			■						
Flow & spatial distrib. of shpmnts	Distance of shipment			■						
Firm characteristics	Shippers and receivers situated on rail line				■					
	Shippers near highway				■					
	Firms own small trucks				■					
Flow & spatial distrib. of shpmnts	Shipment frequency					■				
Modal characteristics	Capacity					■				
	Equipment availability					■				
	Handling quality - damace loss reputation					■				
Total logistics cost	Order and handling costs						■			
	Loss and damage costs							■		
	Inventory carrying cost at destination							■		
	Unavailability of equipment costs							■		
	Intangible service costs								■	
Modal characteristics	Customer service									■
Firm characteristics	Firm size	Background throughout process								

Table 4-9: Respondent Interview Worksheet (Source: FDOT 2002)

Choice Factor	Question/s to be asked
Contact Name: **Title:** **Tel #** **Firm:** **Location:** **Interview Date:** **Time:**	
Choice Factor	**Question/s to be asked**
Physical Attributes of Goods	
	• Shipment size? • Shipment package characteristics? • Shipment self-life? • Shipment value?
Flow/Spatial Distribution of Shipment	
	• What is your shipment frequency? • What is the average shipment distance?
Mode Used	
	• Which modes (mode) are used for freight transportation? • Do you ship intermodally?
Mode Decision	
	• How do you decide on transportation mode? • What shipment characteristics do you consider most important: price, reliability or speed? • Is reliability and speed important due to any customer contracts/guarantees? • Have you used rail in the past? • Have you been satisfied/dissatisfied and why? • Is rail frequency a problem (e.g. South Florida freight trains only run at night)? • How is the decision researched? Do they use a freight-forwarder? • Do you use one or many trucking companies? • Do you have contracts with trucking companies? If so, was rail considered before entering into such contracts? • Is rail an option? • Was highway proximity considered when deciding on location?
Accessibility / Location	
	• Is rail an option? • Are you near a railhead? • Would you consider using truck to get to rail • How did your firm decide upon its current location? • Was rail accessibility considered when deciding on a location? • Was highway proximity considered when deciding on a location? • If rail were accessible, would you consider using it? • If rail is not accessible, are you satisfied with this?, would you consider using it?
Future Plans	
	• Are you looking to relocate closer to rail? • Are you looking to build rail connections to make it accessible? • Is rail part of your company's long-term transportation goals? • What would rail have to do to become part of your future goals (e.g. increase reliability, increase shipment frequency etc)?

Costs and accuracy of data for different survey types varies. For example, telephone interviews permit relatively easy follow-up, often provide more detailed and direct information and are flexible and often providing useful information throughout the interview beyond the scope of structured questions. Shortcomings of this approach are: they are more time consuming (and costly) than alternative methods; the potential for lack of uniformity among interview structure; purposeful sampling (as opposed to random); respondent availability issues; and that this approach is not feasible for large numbers or surveys (FDOT).

CHAPTER 5: CONCLUSIONS

Freight demand modeling has been an increasing concern by state Department of Transportation and regional planning agencies. Approaches to address commodity flows and heavy vehicle traffic necessitate further studies to improve the current planning models. MAP-21 also plans to develop a national freight plan because of the growing needs of consumers on various commodities with limited transportation network to support the demand. Statewide travel demand models over the years have focused upon passenger travel, but with recent growth in freight, traffic agencies are now more concerned to include the freight component in travel demand modeling. Some statewide travel demand models have incorporated freight component, but freight mode choice was not considered. There are two fold reasons: first, unavailability of freight origin-destination and commodity data,; second, the difficulty in modeling behaviors of shippers in relation to the commodity type and urgency of shipment. With a number of new initiatives at the global and national levels such as the Panama Canal expansion, opening of the Northwest Passage, construction of freight alone corridors and the addition of new freight rail tracks, it is imperative to determine the freight mode choice to know which mode is preferable for which commodity and with increasing demand which modes will be chosen so that state agencies can prepare infrastructure needs to meet the future demand.

FAF was the only open source data available for analyzing freight mode choice with limited aggregated commodity flow data. Relevant factors with the mode choice were examined to provide implications for policy, freight planning, and decision making. A multivariate logistic model was developed to accomplish the project goals with aggregate shipment data, model formulation, empirical analysis and model application were discussed. The model was designed to explore the relationship between truck share and origin and destination zone characteristics. MD was used as the study area.

With the available data, a set of three groups of commodities (lower-less than 40%, medium-between 40%-80% and higher truck percentage-more than 80%) were proposed as a super set of 46 FAF commodity types. Further, separate models were proposed for To, and From MD. It is reasonable to expect that bulk of within MD shipments will happen via truck. So, may not require further modeling. In addition, three FAF zones within MD is not a reasonable data set for modeling freight mode choice within MD.

Mode choice models for trucks and rails were developed for from and to MD. Other modes did not contain sufficient data to develop models. It was found that for all commodities truck and rail in combination carried more than 95% of the mode share. Truck share is highly influenced by the OD distance. The number of distribution centers, highway/rail coverage and employment are also significant in the model. For the commodities with low truck share, the number of truck and rail centers will influence the percentage of tonnage shipped by truck. For the commodities with medium truck share, the percentage of truck tonnage only depends on the characteristics of the opposite zones. Variables such as highway and rail coverage in MD and employment in MD are not relevant. The model can be applied to estimate the average change of the truck share or other modes under future planning scenarios.

The research also proposes the need for detailed data for discrete choice modeling to achieve better results. With more data on zonal land use property, relevant factors can be analyzed for useful implications. Also, to achieve better estimation for freight shipment mode choice, other factors such as value of time, accurate shipping costs for each mode, stated preference or revealed preference surveys among the shippers for their decision making will provide a large improvement for the research objectives.

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Appendix-A

Input Data

Table A-1 Highway and Railway distance between all zones to MD zones.

Zone	Highway			Rail		
	Baltimore MD MSA	Washington DC-VA-MD-WV MSA (MD	Remainder of Maryland	Baltimore MD MSA	Washington DC-VA-MD-WV MSA (MD	Remainder of Maryland
1	767.09	733.07	827.28	806.69	794.88	894.09
2	970.07	936.05	1013.34	1022.93	1011.12	1071.19
3	794.92	760.9	847.08	840.29	828.49	891.63
4	4500	4500	4500	9999999999	9999999999	9999999999
5	2242.55	2223.01	2325.49	2509.71	2496.93	2612.51
6	2276.83	2257.3	2359.78	2405.63	2387.97	2508.44
7	2180.02	2160.49	2262.96	2458.27	2415.35	2585.71
8	1045.13	1011.11	1105.32	1137.13	1125.32	1254.05
9	2517.94	2498.41	2600.89	2716.79	2674.61	2844.23
10	2663.84	2644.3	2746.78	2866.16	2823.98	2993.6
11	2558.73	2539.2	2641.68	2940.51	2897.59	3057.08
12	2779.27	2759.74	2862.21	3007.69	2965.51	3135.13
13	2700.96	2681.43	2783.91	3034.41	2992.23	3161.84
14	1591.37	1571.83	1674.31	1789.65	1747.47	1917.09
15	1638.15	1618.62	1721.09	1822.99	1780.81	1950.43
16	307.37	347.84	341.16	321.54	378.82	365.37
17	265.86	306.33	299.65	288.79	346.06	332.62
18	308.1	348.57	341.89	331.94	389.22	375.78
19	98.49	115.02	58	115.75	170.64	63.52
20	41.55	17.69	101.77	41.97	21.81	204.39
21	756.72	729.66	757.71	802.97	791.16	778.17
22	1078.56	1051.5	1079.55	1142.73	1130.92	1117.93
23	870.99	843.93	871.98	952.68	940.87	927.88
24	918.85	891.79	919.84	1004.21	992.4	979.41
25	868.44	841.39	869.43	892.63	880.82	867.83
26	664.29	627.52	707.89	687.87	676.06	736.13
27	632.49	605.43	633.48	667.32	655.51	642.52
28	692.6	660.61	708.07	777.75	765.94	765.96
29	9999999999	9999999999	9999999999	9999999999	9999999999	9999999999
30	9999999999	9999999999	9999999999	9999999999	9999999999	9999999999
31	2264.37	2256.03	2356.14	2550.74	2507.82	2675.02
32	697.16	688.83	788.94	797.86	755.68	925.3
33	782.3	762.77	865.24	949.96	907.78	1078.81
34	737.5	717.96	820.44	876.76	834.58	1004.2
35	647.89	639.56	739.67	785.52	743.34	912.96
36	564.31	544.78	647.26	710.36	668.18	845.49
37	594.76	575.23	677.71	720.05	677.87	850.23
38	997.7	989.37	1089.48	1089.59	1047.41	1217.03
39	1071.23	1051.7	1154.17	1228.99	1186.81	1356.43
40	1274.09	1254.56	1357.03	1471.04	1428.86	1598.48
41	606.54	587.01	686.71	750.29	708.1	885.63
42	605.63	583.65	677.91	826.39	784.21	961.74
43	1148.89	1114.87	1209.08	1231.58	1219.77	1304.35
44	1279.68	1245.66	1339.87	1372.28	1360.47	1444.93
45	1095.26	1061.24	1153.56	1143.54	1131.73	1225.98
46	1165.08	1131.06	1225.27	1270.74	1258.93	1358.14
47	648.66	689.13	682.45	736.26	793.54	780.1
48	10	43.42	98.17	10	61.72	169.26
49	43.3	10	114.48	61.72	10	224.15
50	97.95	114.48	10	169.26	224.15	10
51	377.05	417.52	410.84	411.15	468.43	454.99
52	339.15	379.62	372.93	356.15	413.43	399.99
53	521.68	513.35	613.46	637.93	595.74	764.95
54	617.7	609.37	709.48	730.15	687.97	857.18
55	720.6	712.27	812.38	835.14	792.95	962.16

56	1101.21	1092.88	1192.99	1204.43	1162.24	1331.86
57	1220.53	1212.19	1312.3	1329.49	1287.3	1456.92
58	971.88	937.86	1032.07	1076.54	1064.73	1163.94
59	1018.6	999.06	1101.54	1168.08	1125.9	1295.52
60	836.22	816.69	919.16	985.38	943.19	1119.85
61	951.83	932.3	1034.78	1102.27	1060.09	1236.74
62	1953.82	1945.48	2045.6	2164.04	2121.86	2291.48
63	1335.89	1327.55	1427.66	1468.63	1426.45	1596.07
64	2352.62	2336.40	2440.91	2720.66	2677.58	2847.20
65	2397.07	2377.54	2480.01	2575.85	2536.01	2701.61
66	474.2	514.67	507.99	528.04	585.32	571.88
67	157.83	198.3	198.1	160.23	217.51	204.07
68	100.`35	140.82	130.96	130.82	188.1	174.65
69	122.49	162.96	104.39	156.71	213.99	200.54
70	1825.64	1806.11	1908.59	1971.02	1928.84	2098.45
71	338.73	378.83	380.04	354.64	411.92	398.48
72	333.3	325.47	425.58	393.89	437.9	493.58
73	230.23	270.7	264.02	237.31	294.59	281.15
74	307.76	330.62	402.05	461.39	505.4	545.49
75	337.7	368.72	397.44	406.91	450.92	478.8
76	406.13	372.11	450.16	412.32	400.51	485.53
77	344.05	310.03	393.81	355.58	343.77	428.78
78	307.15	280.09	326.94	340.36	328.55	327.81
79	341.7	314.65	361.49	369.53	357.72	364.75
80	1516.08	1507.75	1607.86	1654.82	1612.63	1782.25
81	475.8	456.26	558.03	588.9	546.72	724.25
82	334.77	326.44	426.55	465.96	423.78	591.38
83	392.19	372.66	475.13	502.36	460.18	637.71
84	459.8	440.26	542.74	618.09	575.91	748.28
85	444.79	436.46	536.57	561.72	519.54	690.32
86	1300.75	1281.22	1383.69	1491.19	1449.01	1625.66
87	1211.88	1192.35	1294.83	1381.07	1338.89	1515.54
88	1381.8	1362.27	1464.74	1602.14	1559.96	1729.58
89	2756.03	2747.7	2847.81	2957.29	2915.11	3084.73
90	2622.67	2605.91	2708.38	3070.92	3038.03	3198.36
91	101.97	143.11	146.58	128.02	185.3	171.86
92	220.1	211.77	311.88	318.87	276.68	444.28
93	172.9	191.81	267.2	232.78	276.79	332.47
94	342.56	383.03	376.34	375.98	433.25	419.81
95	534.89	507.83	535.88	534.56	522.75	509.76
96	512.2	478.18	555.47	553.34	541.53	589.28
97	500.68	473.63	508.71	556.07	544.26	540.58
98	1430.03	1421.7	1521.81	1544.88	1502.7	1672.31
99	874.09	840.07	934.28	996.28	984.48	1113.2
100	688.58	654.56	748.77	809.74	797.93	926.66
101	642.72	608.7	702.91	804.95	793.14	921.87
102	1517.17	1483.15	1577.36	1608.98	1597.17	1696.38
103	1329.2	1295.18	1389.39	1423.22	1411.41	1497.23
104	1636.42	1602.4	1696.6	1763.82	1752.01	1837.84
105	1359.24	1325.22	1419.43	1449.76	1437.95	1566.68
106	1955.58	1921.56	2015.77	2086.76	2074.95	2189.57
107	1412.88	1378.85	1473.06	1505.94	1494.13	1579.95
108	1728.31	1694.29	1788.5	1814.49	1802.68	1901.89
109	1600.4	1566.38	1660.58	1684.15	1672.34	1771.55
110	1563.99	1529.97	1624.18	1675.08	1663.27	1777.79
111	2100.66	2081.12	2183.6	2316.81	2274.63	2444.25
112	2019.61	2000.08	2102.55	2245.13	2202.20	2372.57
113	459.19	499.29	500.5	504.54	561.82	548.38
114	151.27	124.21	204.67	166.75	154.94	249.21
115	207.9	190.77	164.8	241.26	229.45	323.72
116	83.6	49.58	143.79	98.17	86.36	256.87
117	241.24	207.22	301.43	237.13	225.32	354.05
118	2675.42	2667.08	2767.19	2888.2	2846.02	3015.64

119	2560.47	2552.14	2652.25	2742.67	2700.49	2870.11
120	308.15	286.17	380.42	366.64	324.45	521.16
121	773.74	765.4	865.52	871.15	828.96	998.58
122	954.95	946.62	1046.73	1051.54	1009.35	1178.97
123	1787.12	1778.79	1878.9	1944.31	1902.13	2071.75

Table A-2 Corresponding zone and zone ID

Zone	Zone ID	Zone	Zone ID
Birmingham AL CSA	1	Nebraska	63
Mobile AL CSA	2	Las Vegas NV CSA	64
Remainder of Alabama	3	Remainder of Nevada	65
Alaska	4	New Hampshire	66
Phoenix AZ MSA	5	New York NY-NJ-CT-PA CSA (NJ Part)	67
Tucson AZ MSA	6	Philadelphia PA-NJ-DE-MD CSA (NJ Part)	68
Remainder of Arizona	7	Remainder of New Jersey	69
Arkansas	8	New Mexico	70
Los Angeles CA CSA	9	Albany NY CSA	71
Sacramento CA-NV CSA (CA Part)	10	Buffalo NY CSA	72
San Diego CA MSA	11	New York NY-NJ-CT-PA CSA (NY Part)	73
San Francisco CA CSA	12	Rochester NY CSA	74
Remainder of California	13	Remainder of New York	75
Denver CO CSA	14	Charlotte NC-SC CSA (NC Part)	76
Remainder of Colorado	15	Greensboro--Winston-Salem--High Point NC CSA	77
Hartford CT CSA	16	Raleigh-Durham NC CSA	78
New York NY-NJ-CT-PA CSA (CT Part)	17	Remainder of North Carolina	79
Remainder of Connecticut	18	North Dakota	80
Delaware	19	Cincinnati OH-KY-IN CSA (OH Part)	81
Washington DC-VA-MD-WV MSA (DC Part)	20	Cleveland OH CSA	82
Jacksonville FL MSA	21	Columbus OH CSA	83
Miami FL MSA	22	Dayton OH CSA	84
Orlando FL CSA	23	Remainder of Ohio	85
Tampa FL MSA	24	Oklahoma City OK CSA	86
Remainder of Florida	25	Tulsa OK CSA	87
Atlanta GA-AL CSA (GA Part)	26	Remainder of Oklahoma	88
Savannah GA CSA	27	Portland OR-WA MSA (OR Part)	89
Remainder of Georgia	28	Remainder of Oregon	90
Honolulu HI MSA	29	Philadelphia PA-NJ-DE-MD CSA (PA Part)	91
Remainder of Hawaii	30	Pittsburgh PA CSA	92
Idaho	31	Remainder of Pennsylvania	93
Chicago IL-IN-WI CSA (IL Part)	32	Rhode Island	94
St. Louis MO-IL CSA (IL Part)	33	Charleston SC MSA	95
Remainder of Illinois	34	Greenville SC CSA	96
Chicago IL-IN-WI CSA (IN Part)	35	Remainder of South Carolina	97
Indianapolis IN CSA	36	South Dakota	98
Remainder of Indiana	37	Memphis TN-MS-AR MSA (TN Part)	99
Iowa	38	Nashville TN CSA	100
Kansas City MO-KS CSA (KS Part)	39	Remainder of Tennessee	101
Remainder of Kansas	40	Austin TX MSA	102
Louisville KY-IN CSA (KY Part)	41	Beaumont TX MSA	103
Remainder of Kentucky	42	Corpus Christi TX CSA	104
Baton Rouge LA CSA	43	Dallas-Fort Worth TX CSA	105
Lake Charles LA CSA	44	El Paso TX MSA	106
New Orleans LA CSA	45	Houston TX CSA	107
Remainder of Louisiana	46	Laredo TX MSA	108
Maine	47	San Antonio TX MSA	109
Baltimore MD MSA	48	Remainder of Texas	110
Washington DC-VA-MD-WV MSA (MD Part)	49	Salt Lake City UT CSA	111
Remainder of Maryland	50	Remainder of Utah	112
Boston MA-NH CSA (MA Part)	51	Vermont	113
Remainder of Massachusetts	52	Richmond VA MSA	114
Detroit MI CSA	53	Norfolk VA-NC MSA (VA Part)	115
Grand Rapids MI CSA	54	Washington DC-MD-VA-WV CSA (VA Part)	116
Remainder of Michigan	55	Remainder of Virginia	117
Minneapolis-St. Paul MN-WI CSA (MN Part)	56	Seattle WA CSA	118
Remainder of Minnesota	57	Remainder of Washington	119
Mississippi	58	West Virginia	120
Kansas City MO-KS CSA (MO Part)	59	Milwaukee WI CSA	121
St. Louis MO-IL CSA (MO Part)	60	Remainder of Wisconsin	122
Remainder of Missouri	61	Wyoming	123

Montana	62

Table A-3 Highway and Railway network length (miles) in FAF zone

zone ID	rail	Principal Arterials highway	Other Highway	zone ID	rail	Principal Arterials highway	Other Highway
1	1133.787	669.65	784.86	63	6052.768	3982.51	4703.34
2	273.1192	343.99	209.45	64	207.7919	640.87	494.45
3	3785.372	3195.36	4191.75	65	1699.039	1560.79	2330.15
4	620.0958	1809.93	4714.9	66	811.7	865.84	924.91
5	644.706	1195.51	612.56	67	1390.385	1715.45	456.28
6	201.3044	307.4	303.92	68	433.3053	612.57	207.78
7	1967.511	1812.64	2532.34	69	239.0964	292.76	95.8
8	4000.084	3773.36	4716.24	70	2731.354	3541.7	5502.28
9	2336.865	5608.42	1582.45	71	878.7873	930.32	1388.99
10	703.9075	1084.62	566.23	72	815.163	722.34	587.77
11	230.5085	706.38	286.43	73	1108.716	2713.86	1068.26
12	1092.601	1945.53	748.8	74	868.6	832.94	982.64
13	4775.725	5379.53	5438.44	75	2839.23	2771.6	4984.01
14	877.7006	1297.29	753.15	76	662.5913	895.4	443.06
15	3154.619	3030.08	4008.06	77	554.2818	792.33	530.38
16	318.0808	584.26	429.76	78	547.1303	698.95	474.16
17	349.9471	686.72	430.69	79	2833.664	2965.63	3430.33
18	67.4343	143.91	143.11	80	5330.025	3870.98	3590.83
19	304.3658	414.54	228.16	81	576.8461	792.01	286.35
20	36.00672	111.13	20.8	82	1314.783	1345.94	327.37
21	472.7243	601.24	331.1	83	1224.848	840.61	617.12
22	437.1848	1106.93	190.72	84	682.2127	531.35	268.84
23	610.5443	1211.1	506.12	85	5777.295	3597.8	2121.53
24	501.4594	723.28	190.01	86	650.0303	749.27	575.64
25	3100.75	4295.95	3100.98	87	734.4396	636.02	532.13
26	1279.914	2132.65	1433.83	88	4393.971	2712.86	4080.29
27	315.7695	312.73	229.13	89	471.644	608.73	351.07
28	4349.866	4959.53	6926.76	90	3129.798	4006.76	2489.16
29	30.60665	160.76	67.62	91	1146.967	1482.08	393.27
30	4.794327	185.49	738.66	92	2095.179	1504.97	808.9
31	2997.04	2529.57	2375.7	93	6753.056	4938.04	4501.14
32	2548.953	2420.96	330.91	94	145.0411	575.81	64.51
33	1002.358	614.66	447.71	95	333.6877	329.07	167.81
34	8787.399	4539.95	4911.29	96	661.6861	770.19	754.76
35	1063.53	535.7	178.78	97	2609.003	2511.1	2720.39
36	1176.931	1038.08	583.08	98	3618.135	3587.53	3420.59
37	5274.586	3053.35	2368.66	99	336.0881	451.86	118.78
38	7898.955	5591.98	4414.35	100	587.0082	1108.44	531.29

39	635.3144	510.78	238.61	101	2976.91	3686.35	2560.17
40	7907.817	4707.94	5153.87	102	395.9912	554.26	346.64
41	431.128	560.15	323.37	103	421.5995	321	171.35
42	3845.495	3657.13	3180.32	104	289.7426	278.1	205.35
43	533.9715	388.36	292.06	105	2013.201	2816.71	905.52
44	227.5504	160.65	300.21	106	110.9509	285.88	33.12
45	599.7042	470.22	370.98	107	1635.981	2114.47	681.51
46	3155.216	2276.33	3253.45	108	95.11093	133.44	23.18
47	1828.887	1512.93	2455.3	109	433.4275	789.06	461.46
48	539.8446	800.8	375.05	110	10529.05	9731.38	13034.03
49	300.2932	649.53	254.71	111	1161.606	748.56	516.24
50	654.8337	503.73	517.24	112	1151.629	1582.33	2169.39
51	1201.819	1988.42	324.02	113	787.1855	854.15	1183.46
52	515.5475	798.65	241.62	114	609.1501	738.36	608.86
53	1437.805	2077.25	476.02	115	411.237	494.4	280.74
54	614.3923	647	428.46	116	330.1255	778.66	296.08
55	4945.772	4254.55	3211.41	117	3038.199	2325.25	2801.44
56	1650.353	1185.44	1603.58	118	1235.024	1575.27	752.61
57	6513.45	3968.55	6128.26	119	4634.494	2902.98	3088.35
58	4052.098	4110.44	4857.31	120	4012.656	2242.72	2654.92
59	1034.924	952.6	199.36	121	538.3881	820.42	266.12
60	742.9752	1013.13	309.47	122	5813.478	4719.3	6078.41
61	4742.792	4138.93	3534.5	123	2734.025	3211.99	3206.02
62	5383.886	4160.34	3479.51				

Table A-4Number of intermodal facilities in FAF zone

zone ID	Rail	Truck	Port	Other	zone ID	Rail	Truck	Port	Other
1	22	3	0	6	63	39	6	0	2
2	6	2	0	1	64	1	1	0	4
3	19	2	3	2	65	5	1	0	2
4	1	1	10	4	66	1	3	0	3
5	12	2	0	9	67	39	9	1	7
6	1	1	0	3	68	14	1	1	0
7	3	3	0	2	69	1	0	0	0
8	25	11	2	3	70	5	4	0	3
9	59	10	3	15	71	7	2	1	2
10	4	2	1	5	72	17	1	1	3
11	4	2	1	4	73	5	12	1	19
12	22	10	4	9	74	6	1	0	2
13	37	11	2	3	75	5	7	2	3
14	18	5	0	5	76	20	1	0	6
15	6	4	0	3	77	12	3	0	2
16	3	1	0	2	78	7	1	0	2
17	4	4	2	1	79	10	4	1	2
18	1	0	1	0	80	49	7	0	3
19	11	1	1	0	81	26	1	1	1
20	1	0	0	0	82	42	1	4	3
21	17	2	2	1	83	28	1	1	6
22	14	3	3	13	84	10	1	0	4
23	4	3	0	7	85	44	6	6	4
24	5	1	2	5	86	11	1	0	2
25	7	8	5	4	87	11	2	1	1
26	39	4	0	9	88	11	0	1	0
27	7	3	2	1	89	30	3	3	3
28	27	6	2	0	90	12	5	12	0
29	0	0	0	4	91	35	3	3	5
30	0	0	0	1	92	18	2	1	3
31	11	3	1	2	93	51	7	1	6
32	101	12	3	13	94	0	1	1	1
33	21	0	2	1	95	10	4	1	4
34	55	10	1	8	96	14	1	0	1
35	13	1	2	0	97	5	4	0	2
36	19	2	0	5	98	16	6	0	2
37	43	11	3	5	99	26	6	1	4
38	66	8	1	4	100	5	1	3	2
39	18	2	5	1	101	31	9	0	4
40	41	7	0	2	102	6	1	0	1
41	18	1	1	3	103	3	3	5	0
42	17	8	3	6	104	5	2	7	0
43	3	2	2	0	105	33	7	0	4
44	1	0	3	0	106	8	1	0	1
45	21	3	3	3	107	31	3	8	7

46	6	4	5	2	108	3	1	0	3
47	8	3	3	3	109	11	1	0	3
48	16	2	9	4	110	18	12	2	5
49	0	1	0	0	111	8	1	0	4
50	3	2	0	0	112	0	0	0	0
51	40	6	3	4	113	4	2	0	2
52	15	3	0	0	114	11	1	1	3
53	44	4	4	5	115	11	1	3	1
54	14	1	7	1	116	4	2	1	4
55	40	8	4	3	117	13	2	0	1
56	31	6	16	8	118	42	4	5	11
57	27	6	12	0	119	34	6	13	3
58	13	11	3	3	120	5	2	3	2
59	43	3	3	4	121	6	1	1	6
60	20	5	3	4	122	34	9	6	1
61	16	6	5	2	123	5	3	0	0
62	18	4	0	2					

Table A-5 Work based FAF zone transportation related employments

zone ID	Frequency	Percentage	zone ID	Frequency	Percentage
1	16538	3.06%	63	81892	4.61%
2	9834	4.27%	64	32893	3.55%
3	32121	2.89%	65	14008	4.20%
4	39598	6.81%	66	27268	2.23%
5	60212	3.27%	67	141933	4.65%
6	7059	1.97%	68	24332	4.08%
7	7327	2.00%	69	4219	2.03%
8	116720	5.16%	70	40316	2.60%
9	245883	3.44%	71	16649	3.17%
10	22083	2.59%	72	20263	3.53%
11	21089	1.71%	73	200822	3.70%
12	102390	3.09%	74	10687	2.02%
13	55822	2.77%	75	30732	2.95%
14	51663	3.65%	76	38316	4.04%
15	15158	1.94%	77	29539	4.18%
16	18363	2.79%	78	15058	1.91%
17	19942	2.32%	79	35233	2.44%
18	3089	2.60%	81	34387	4.20%
19	22046	2.67%	82	46514	3.36%
20	6870	1.11%	83	48968	5.15%
21	32235	4.75%	84	14699	3.26%
22	86987	3.78%	85	47502	3.17%
23	35083	2.85%	86	13161	2.33%
24	24239	1.98%	87	17513	4.02%
25	43309	1.85%	88	11849	2.56%
26	115987	4.73%	89	33811	3.85%
27	10722	6.60%	90	21257	2.72%
28	36354	2.82%	91	59829	3.03%
29	25010	6.76%	92	45354	4.02%
30	6777	4.58%	93	116237	4.94%
31	18500	2.90%	94	20496	2.17%
32	175126	4.37%	95	11256	4.05%
33	11251	4.72%	96	18195	3.33%
34	50696	3.58%	97	23169	2.25%
35	11837	3.70%	98	19276	2.63%
36	54813	5.48%	99	53759	10.59%
37	48395	3.17%	100	30881	3.85%
38	109810	3.79%	101	55977	4.04%
39	19724	4.43%	102	10954	1.44%
40	22109	2.50%	103	4747	2.94%
41	39814	7.25%	104	4617	2.64%
42	45304	3.75%	105	142363	4.84%
43	9860	2.69%	106	17745	5.97%

44	3406	3.76%	107	112739	4.56%
45	21510	4.47%	108	13419	16.81%
46	35350	4.20%	109	22638	2.89%
47	30900	2.71%	110	61964	2.82%
48	39068	3.23%	111	36924	4.54%
49	24000	2.60%	112	10729	2.99%
50	8873	3.43%	114	21095	3.44%
53	65079	2.92%	115	20756	2.96%
54	12491	2.13%	116	36864	2.91%
55	27526	2.24%	117	29375	3.16%
56	55298	3.02%	118	74661	4.05%
57	25022	3.20%	119	23813	2.62%
58	80134	3.62%	120	39568	2.89%
59	22443	4.07%	121	30582	3.34%
60	37426	3.41%	122	66701	3.70%
61	36927	3.77%	123	17448	3.29%
62	23082	2.76%			

Table A-6 Value/weight (1,000$/ton) of the commodity

Commodity	To MD	From MD	Within MD	Commodity	To MD	From MD	Within MD
Alcoholic beverages	1.7264	1.3084	2.1619	Metallic ores	5.0481	1.3591	0.0409
Animal feed	0.6277	0.5759	0.3764	Milled grain prods.	1.0760	1.3770	1.0266
Articles-base metal	3.9423	3.3811	2.8301	Misc. mfg. prods.	6.3743	6.5561	4.7602
Base metals	1.0547	1.5609	1.5425	Mixed freight	4.0955	3.5913	2.4920
Basic chemicals	0.5948	1.2723	0.6357	Motorized vehicles	6.3086	9.8348	6.9074
Building stone	0.0995	0.3075	0.1151	Natural sands	0.0152	0.0205	0.0124
Cereal grains	0.1794	0.1519	0.1601	Newsprint/paper	0.6935	0.7744	1.2766
Chemical prods.	1.8056	3.6356	3.5738	Nonmetal min. prods.	0.2064	0.6006	0.1377
Coal	0.0472	0.0585	0.0465	Nonmetallic minerals	0.1517	0.0856	0.0331
Coal-n.e.c.	0.3647	0.4809	0.3647	Other ag prods.	1.0699	1.0191	0.6120
Crude petroleum	0.5063	0.4865	0.5110	Other foodstuffs	0.6042	1.1606	1.0328
Electronics	19.4793	17.5420	15.5387	Paper articles	1.5612	1.7972	1.5575
Fertilizers	0.1603	0.2299	0.1638	Pharmaceuticals	43.2480	77.3466	72.0809
Fuel oils	0.5322	0.6238	0.5714	Plastics/rubber	2.4516	3.1294	2.9479
Furniture	3.0683	5.6630	4.0383	Precision instruments	36.3279	115.7896	15.1710
Gasoline	0.6659	0.6387	0.6553	Printed prods.	2.8787	3.9881	4.2260
Gravel	0.0098	0.0126	0.0109	Textiles/leather	25.1913	11.9936	12.2825
Live animals/fish	1.0768	1.1457	1.4225	Tobacco prods.	29.2822	23.9553	22.9717
Logs	0.1390	0.3148	0.0652	Transport equip.	65.6416	36.2781	88.7130
Machinery	7.2277	5.3851	7.9865	Waste/scrap	0.1835	0.2428	0.0684
Meat/seafood	2.8044	3.2760	3.3700	Wood prods.	0.6963	0.6399	0.6648

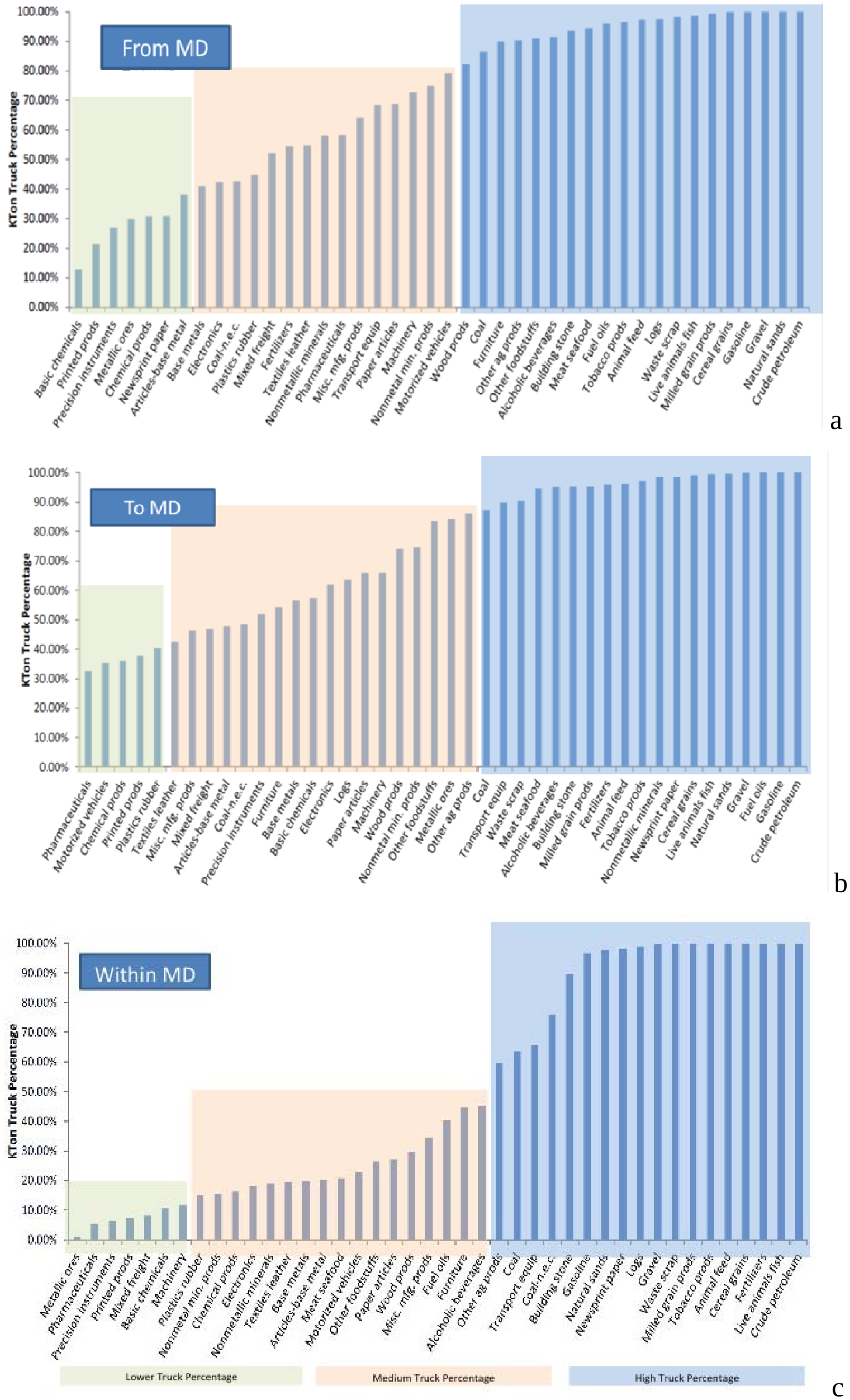


Figure A-1 Ordered commodities by truck share

Appendix-B

MSTM Truck Model

(Modified version adapted from Maryland Statewide Transportation Model)

Freight Model

Statewide Layer

The statewide level truck trip model is an adaption of the BMC and MWCOG truck and commercial vehicles models. Two truck types, Medium Truck and Heavy Truck, and commercial vehicles are distinguished. Trip generation is based on employment by category and total households. BMC truck generation rates are presented in Table B-1. Comparative generation rates for other areas are given in Table B-2, showing that BMC truck trip generation rates are comparable to rates applied in other regions. Trips ends are calculated for the statewide level model area.

Table B-1: BMC Commercial Vehicle Generation Rates

Generation Variable	Commercial Vehicle Generation Rates		
	Light (4-Tire)	Medium Truck	Heavy Truck
Employment:			
Industrial	0.454	0.125	0.179
Retail	0.501	0.124	0.127
Office	0.454	0.034	0.026
Households	0.146	0.048	0.061

Table B-2: Comparative Commercial Vehicle Generation Rates

Model	Households	Employment Agriculture	Manufacture	Wholesale	Retail	Service	Other
QRFM	0.251	1.110	0.938	0.938	0.888	0.437	0.663
Phoenix	0.154	0.763	0.641	0.763	0.591	0.309	0.763
Columbus	0.134	0.506	0.506	0.506	0.437	0.233	0.506
Atlanta	0.140	0.482	0.482	0.482	0.643	0.232	0.232
Huston	0.020	0.300	0.480	0.300	0.360	0.300	0.300
Seattle	0.093	0.410	0.347	0.347	0.328	0.162	0.245
Vancouver	0.019	0.096	0.069	0.071	0.143	0.043	0.229

Regional Layer

Truck trip distribution is based on a gravity model formulation using truck generalized cost incorporating truck travel times, travel cost and tolls. The current implementation uses truck travel time in the off-peak time period. The initial truck distribution parameters were borrowed from the BMC Truck Model and the BMC Commercial

Vehicles Model. As the gamma parameter was set to 0 in the BMC model, the gravity formulation technically becomes an exponential function (because exp(0) = 1).

$$F_{i,j} = \alpha \cdot t_{i,j}{}^{\beta} \cdot \exp(\gamma \cdot t_{i,j})$$

Where

$F_{i,j}$ Friction factor from zone i to j

$T_{i,j}$ Off peak travel time from i to j

α, β, γ Parameters defined below

Table B-3: Friction Factors for the Statewide Truck Model

Original BMC Parameters

Parameter	CommercialVehicles	MediumHeavyTrucks	HeavyHeavyTrucks
Alpha	1,202,604.28	1,202,604.28	3,269,017.37
Beta	-3.75	-5.8	-2.9
Gamma	0	0	0

Adjusted MSTM Parameters

Parameter	CommercialVehicles	MediumHeavyTrucks	HeavyHeavyTrucks
Alpha	1,202,604.28	1,202,604.28	3,269,017.37
Beta	*-8.75*	*-6.8*	*-3.9*
Gamma	0	0	0

Freight-Economy Reconciliation

This section describes the reconciliation of the economic data with the FAF. Inforum[1] has assembled a database of historical and projected freight shipments published in the 2002 Freight Analysis Framework (FAF), which is produced by the U.S. Department of Transportation. The FAF “estimates commodity flows and related freight transportation activity among states, regions, and major international gateways.” This database covers the periods 2002, 2010, 2015, 2020, 2025, 2030, and 2035. Shipments are measured in thousands of tons; shipments in millions of dollars also are available but are not included in this work. The data are published in four sets: domestic freight; US-Canada and US-Mexico land freight; international sea freight; and international air freight. Detail is available for 138 regions, including 114 domestic regions, 17 domestic ports, and 7 international regions. Detail also includes 43 commodities and 7 transportation modes. For each commodity and each mode, nonzero values are published for shipments from region to region. For international shipments, either the origin or destination may be a foreign region. For these international exchanges, a US port is listed; ports may be one of the 17 designated ports, or the “port” may be one of the 114 domestic regions.

After assembling the published FAF data, the data were aggregated in three parts, preserving detail on 131 regions and all 43 commodities. The three parts are total domestic-domestic shipments, exports, and imports. Because the focus of this study is the trucking mode, a second corresponding set of databases were constructed from FAF Truck and International Air records. For each commodity, there are region-region tables of total shipments and truck shipments for domestic trade, exports, and imports.

For each commodity, the regional detail was aggregated to calculate total shipments, shipments by truck, total consumption, and total consumption of goods shipped by truck. Shipments were defined as domestic-domestic trade plus exports. Consumption was defined as domestic-domestic trade plus imports.

[1] Inforum, an economic forecasting and research group at the University of Maryland that has been in operation since 1967, employs interindustry-macroeconomic general equilibrium models to examine past employment trends and to forecast future employment across sectors of the economy. Their primary model, LIFT (Long-term Interindustry Forecasting Tool), uses a bottom-up approach to make such predictions, meaning that it uses component data within each of its defined industries to estimate future employment rather than starting with top-level macroeconomic indicators. In this regard, the model is well-suited to address the questions posed in this report, which focus on commodity shipments. The LIFT model aggregates the North American Industry Classification System (NAICS) industries into 97 industries that span the economy. Inforum maintains a second US model, Iliad, that offers detail on 360 commodities formed from NAICS data.

The FAF database is compiled from information published in Bureau of Transportation's Commodity Flow Survey (CFS); Surface Transportation Board's Carload Waybill Sample; U.S. Army Corps of Engineers (USACE) waterborne commerce data; Bureau of Transportation Statistics' Transborder Surface Freight database; and the Air Freight Movements database from BTS. Each of the 43 commodities employed in the FAF is defined according to the Standard Classification of Transported Goods (SCTG).[2]

These classification codes were compared to the commodity detail employed in the Inforum Lift and Iliad inter-industry macroeconomic models, where the industry details are derived from data published according to the North American Industrial Classification System (formerly the Standard Industrial Classification system). Industry production data employed by Inforum models are primarily derived from BEA's Gross Output by Industry. Gross output represents the market value of an industry's production of goods and services. Data are compiled at the Bureau of Economic Analysis (BEA) using publications from U.S. Department of Agriculture (USDA), U.S. Geological Survey (USGS), Department of Energy (DOE), Census, Bureau of Labor Statistics (BLS), and BEA.[3] In addition to Gross Output, other sources of industry production information utilized by Inforum's models include BEA's Input Output tables and Foreign Trade data from Census. For each commodity defined in the models, the models offer real output, exports, and imports. For each SCTG commodity employed in the FAF, a match was found in the Inforum models, where the match sometimes was the sum of several narrowly defined commodities. This information is used as the basis of model-derived indexes for each of the SCTG commodities for output, exports, and imports.

For each FAF commodity, for domestic shipments, exports, and imports, we calculate from the FAF projections a forecast of the share of truck shipments relative to total (all transportation modes) shipments. These projected shares are employed to adjust our indexes for domestic supply, exports, and imports. These adjustments yield indexes for truck shipments of domestically produced and consumed products, truck shipments of exported goods, and truck shipments of imported goods, where the shipments are measured in constant dollars. Next, these constant-dollar truck shipment levels are scaled to the corresponding 2002 FAF levels, for domestic shipments, exports, and imports for each commodity. This yields model-based history and forecasts of tons of each commodity shipped by truck. The model-based indexes are consistent with the FAF 2002 survey data.

The FAF projections of shipments by truck were updated by scaling the sum of the regional detail to corresponding model-derived totals. For each FAF commodity, the sum (across domestic regions) of domestic shipments was scaled to the model-derived total. This was done both for domestic shipments and domestic

[2] Information on SCTG was found at http://www.statcan.ca/english/Subjects/Standards/sctg/sctg-class.htm#19.

[3] More information may be found at http://www.bea.gov/scb/account_articles/national/0600gpi/tablek1.htm.

consumption. In similar fashion, the sum of FAF exports and imports were scaled to the model-derived totals. Finally, total truck shipments were calculated by adding the detail. Total shipments are the sum of domestic shipments plus exports. Total consumption is the sum of domestic consumption plus imports.[4]

Total shipments and total consumption projections are provided for each commodity and each region. 2002 levels are consistent with FAF levels. Data for 2005 to 2030, in five-year intervals, are provided according to the methodology described above, where the sums of the original FAF figures are controlled to model-derived totals. Estimates for 2000 are constructed by using 2002 FAF regional distributions and trucking shares and where the total shipments are controlled to the model-derived index levels for 2000.

A series of 43 worksheets contain information on each FAF commodity. Total truck shipments and total consumption of truck freight, calculated from the FAF database, are provided, together with corresponding model-derived aggregate indexes. FAF figures are provided for 2002 and 2010-2030 in 5-year increments. Model-derived updates are provided for 2000, 2002, and 2005-2030 in 5-year increments. For each commodity, shipments and consumption figures also are provided for each domestic region and port, where the regional detail is consistent with the model-derived totals.

The methodology described here depends on several assumptions that warrant additional investigation. A crucial assumption is that growth of constant-dollar indexes for output, real exports, and real imports corresponds to growth of shipments by weight. This assumption may fail if the economic data are adjusted for quality change or if the nature of the commodity changes over time.

The updated projections and historical estimates seem to offer improvements over the FAF projections. In particular, the effects of the recent recession are clear, though the recession effects are still more clear in the annual economic data. In general, the long-run shipment estimates do not differ dramatically from the FAF projections but arguably are more plausible. Further, the production and consumption totals by zone are classified into the 130x130 matrix format by the internal proportion fitting (IPF) method. INFORUM provides the Production and Consumption by FAF zone as control totals (marginals), and FAF provides the starting

[4] Note that the current work is done slightly differently. The FAF-based detail for commodity shipments by truck are scaled to the model-derived estimates for total shipments, where total shipments are the sum of domestic supply and exports. Similarly, FAF-based detail for receipts are scaled to the sum of model-derived figures for domestic receipts plus imports. This change from the original procedure minimizes problems with the initial results. These problems arose where the FAF forecasts of imports and exports differ substantially from the Inforum forecasts. In the current work, we assume that the foreign shares of commodity shipments implied in the FAF forecasts will hold.

pattern of flows connecting the FAF zones (seed). The IPF process modifies the flows between zones until it matches the INFORUM FAF zones totals. The resulting OD flows is the commodity flow forecast used as the starting demand in the regional truck model.

Update truck model data

The most important input data for the truck model is the Freight Analysis Dataset (FAF), published by the Federal Highway Administration (FHWA). When the truck model was developed initially, the most recent version available was FAF2. In Spring 2010, FWHA released the next update of this dataset, called FAF3. Comparisons between FAF2 and FAF3 showed that the differences are substantial, and FHWA recommends not to use FAF2 anymore. Furthermore, the MSTM methodology to convert FAF data into truck trips was updated significantly. For clarity reasons, the complete revised methodology is documented below, rather than attempting to explain piece-meal-wise every change.

The changes only affect the long-distance model (modeling trips greater than 50 miles). The short-distance model was recalibrated slightly to adjust for changes in the long-distance model. This calibration step is documented below, otherwise the short-distance truck model remains unchanged.

Data

The third generation of the FAF data, called FAF^3, was released in summer 2010 and contains flows between 123 domestic FAF regions and 8 international FAF regions. The MSTM truck model is using the third release of FAF^3, also called FAF3.3. Figure B-1 shows Maryland in Yellow and the Size of the Zones Provided by FAF.

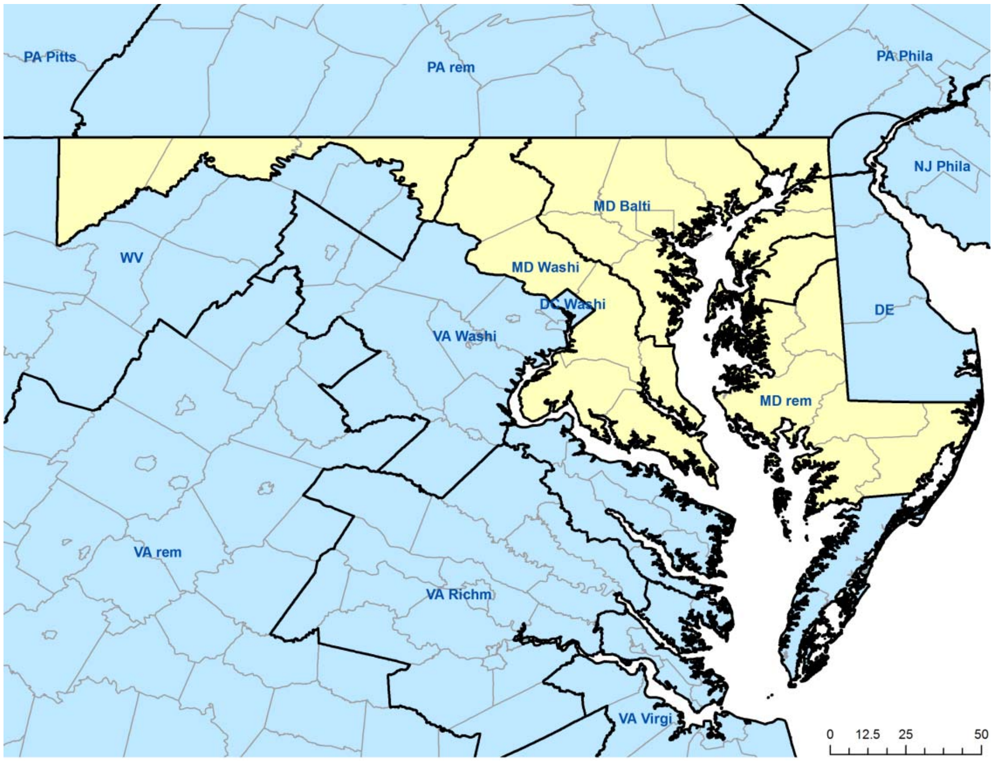


Figure B-1: FAF Zones in Maryland

FAF[3] data provide commodity flows in tons and dollars by

- FAF zones (123 domestic + 8 international zones)
- Mode (7 types)
- Standard Classification of Transported Goods (SCTG) commodity (43 types)
- Port of entry/exit for international flows (i.e. border crossing, seaport or airport)

The base year is 2007, and freight flow forecasts are provided for the years 2015 to 2040 in five-year increments. At this point, the FAF base year 2007, which is coincident with the current MSTM base year, and the forecast for 2030 are used.

The FAF data contains different modes and mode combinations. For the ILLIANA project, the mode Truck is used. Further data required for the truck model include the Vehicle Inventory and Use Survey (VIUS) that was done for the last time in 2002. The U.S. Census Bureau publishes the data with survey records of trucks and their usage[5]. County employment by 10 employment types were collected from the Bureau of Labor Statistics[6],

[5] http://www.census.gov/svsd/www/vius/products.html

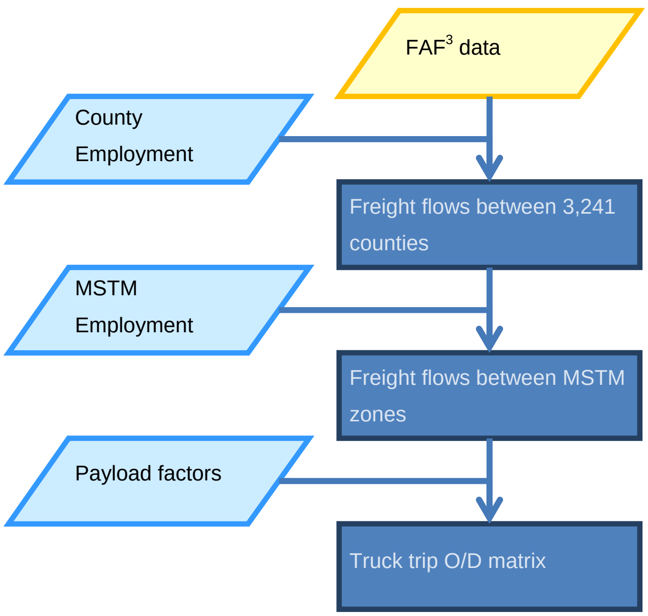
[6] ftp://ftp.bls.gov/pub/special.requests/cew/2010/county_high_level/

and county-level employment for agriculture was collected from the U.S. Department of Agriculture[7]. Input/Output coefficients used for flow disaggregation were provided by the Bureau of Economic Analysis[8]. Finally, MSTM population and employment data are used for truck disaggregation, and truck counts are necessary to validate the model.

Truck model design

The resolution of the FAF data with 123 zones within the U.S. is too coarse to analyze freight flows in Maryland. Hence, a method has been developed to disaggregate freight flows from FAF zones to counties and further to MSTM zones. An overview of the truck model design is shown in Figure B-2. First, the FAF^3 data are disaggregated to counties across the entire U.S. using employment by eleven employment types in each county. Within the MSTM region, detailed employment categories are used to further disaggregate to SMZ. Finally, commodity flows in tons are converted into truck trips using average payload factors.

Figure B-2: Model Design of the Regional Truck Model



Output of this module is a truck trip table between all MSTM zones for two truck types, single-unit trucks and multi-unit trucks.

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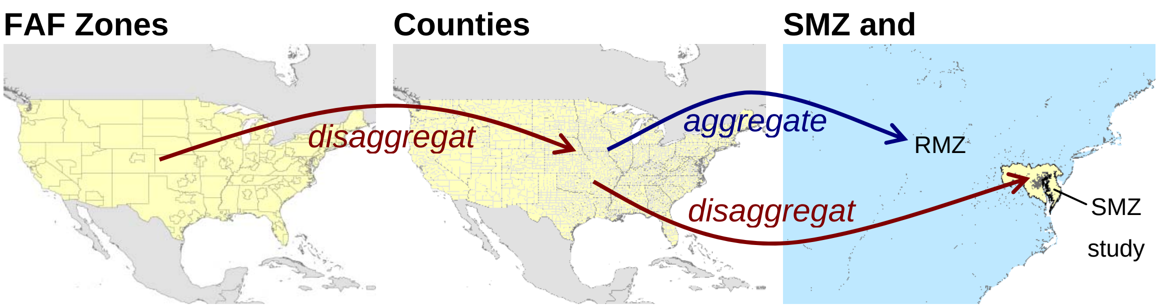
[7]http://www.nass.usda.gov/Statistics_by_Subject/index.php

[8]http://www.bea.gov/industry/io_benchmark.htm

Commodity flow disaggregation

Freight flows are given by FAF zones. For some states, such as New Mexico, Mississippi or Idaho, a single FAF region covers the entire state. Flows from and to these large states would appear as if everything was produced and consumed in one location in the state's center (or the polygon's centroid). To achieve a finer spatial resolution, truck trips are disaggregated from flows between FAF zones to flows between counties based on employment distributions (Figure B-3). Subsequently, trips are further disaggregated to SMZ in the MSTM model area.

Figure B-3: Disaggregation of freight flows



In the first disaggregation step from FAF zones to counties employment by county in eleven categories is used:

- Agriculture
- Construction Natural Resources and Mining
- Manufacturing
- Trade Transportation and Utilities
- Information
- Financial Activities
- Professional and Business Services
- Education and Health Services
- Leisure and Hospitality
- Other Services
- Government

County-level employment for agriculture was collected from the U.S. Department of Agriculture[9]. For all other employment categories, data was retrieved from the Bureau of Labor Statistics[10]. These employment types serve

[9]http://www.nass.usda.gov/Statistics_by_Subject/index.php

to ensure that certain commodities are only produced or consumed by the appropriate employment types. For example, SCTG25 (logs and other wood in the rough) is produced in those zones that have forestry employment (the model uses agricultural employment as a proxy for forestry); this commodity is shipped to those zones that have employment in industries consuming this commodity, particularly manufacturing and construction. At the more detailed level of MSTM zones, four employment categories are available:

- Retail
- Office
- Other
- Total

The following equation shows the calculation to disaggregate from FAF zones to counties. A flow of commodity *c* from FAF zone *a* to FAF zone *b* is split into flows from county *i* (which is located in FAF zone *a*) to county *j* (which is located in FAF zone *b*) by:

$$flow_{i,j,com} = flow_{FAF_a,FAF_b} \cdot \frac{weight_{i,com} \cdot weight_{j,com}}{\sum_{M \in FAF_a} \sum_{N \in FAF_b} weight_{m,com} \cdot weight_{n,com}} \qquad (6)$$

where $flow_{i,j,com}$ = flow of commodity *com* from county *i* to county *j*
$county_i$ = located in FAF_a
$county_j$ = located in FAF_b
$county_m$ = all counties located in FAF_a
$county_n$ = all counties located in FAF_b

To disaggregate flows from FAF zones to counties, employment in the above-shown eleven categories and make/use coefficients are used. The make/use coefficients were derived from input/output coefficients provided by the Bureau of Economic Analysis[11]. These weights are commodity-specific. They are calculated by:

Production

$$weight_{i,com} = \sum_{ind} \left(empl_{i,ind} \cdot mc_{ind,com} \right) \qquad (7)$$

Consumption

$$weight_{j,com} = \sum_{ind} \left(empl_{j,ind} \cdot uc_{ind,com} \right) \qquad (8)$$

[10] ftp://ftp.bls.gov/pub/special.requests/cew/2010/county_high_level/

[11] http://www.bea.gov/iTable/index_industry.cfm

where $emp_{i,ind}$ = the employment in zone *i* in industry *ind*
$mc_{ind,com}$ = make coefficient describing how many goods of commodity *com* are produced by industry *ind*
$uc_{ind,com}$ = use coefficient describing how many goods of commodity *com* are consumed by industry *ind*

Table B-4 shows the make coefficients applied. Many cells in this table are set to 0, as most commodities are produced by a few industries only. No value was available for commodities SCTG09 (tobacco products) and SCTG15 (coal). They were assumed to be produced by agricultural employment and mining, respectively. As only the relative importance of each industry for a single commodity is required, it is irrelevant to which value the entry for these two commodities is set, as long as the industry that produces this commodity is set to a value greater than 0 and all other industries are set to 0.

Table B-4: Make Coefficients by Industry and Commodity

Commodity	Agriculture	Construction	Health	Leisure	Manufacturing	Mining	Retail	Wholesale	Service
SCTG01	811.6238	0	0	0	0	0	0	0	0
SCTG02	198.234	0	0	0	0	0	0	0	0
SCTG03	3669.689	0	0	0	0	324.679	0	0	0
SCTG04	159.456	0	0	0	114.4688	0	0	0	0
SCTG05	0	0	0	0	786.7564	220.2534	0	0	0
SCTG06	0	0	0	0	1289.469	0	0	0	0
SCTG07	205.8607	0	0	0	6551.506	0	0	0	0
SCTG08	0	0	0	0	1150.509	0	0	0	0
SCTG09	1	0	0	0	0	0	0	0	0
SCTG10	0	0	0	0	4.254867	211.2682	0	0	0
SCTG11	0	0	0	0	0.643628	25.07928	0	0	0
SCTG12	0	0	0	0	3.647224	142.1159	0	0	0
SCTG13	0	0	0	0	3.740241	95.63332	0	0	0
SCTG14	0	0	0	0	0	42.32755	0	0	0
SCTG15	0	0	0	0	0	1	0	0	0
SCTG16	0	0	0	0	0	138.1041	0	0	0
SCTG17	0	0	0	0	46.14806	12.86544	0	0	0
SCTG18	0	0	0	0	46.14806	12.86544	0	0	0
SCTG19	0	0	0	0	222.981	156.6388	0	0	0
SCTG20	0	0	0	0	1133.067	7.601936	0	0	0
SCTG21	0	0	0	0	393.104	0	0	0	0
SCTG22	0	0	0	0	267.6962	0	0	0	0
SCTG23	0	0	0	0	1082.518	0	0	0	0
SCTG24	0	0	0	0	1839.762	0	0	0	0
SCTG25	93.52182	5031.908	0	0	0	0	0	0	0
SCTG26	0	0	0	0	7578.98	0	0	0	0
SCTG27	0	0	0	0	392.5042	0	0	0	0
SCTG28	0	0	0	0	3254.577	0	0	0	0
SCTG29	0	0	0	0	621.0631	0	0	0	561.9978
SCTG30	0	0	0	0	747.4527	0	0	0	0
SCTG31	0	0	0	0	1439.455	9.26281	0	0	0
SCTG32	0	0	0	0	3039.151	0	0	0	0
SCTG33	0	0	0	0	4198.737	0	0	0	0
SCTG34	0	0.067042	0	0	3546.295	0	0	0	0

SCTG35	0	0	0	0	12377.87	0	0	0	0
SCTG36	0	0	0	0	6003.092	0	0	0	0
SCTG37	0	0	0	0	1785.718	0	0	0	0
SCTG38	0	0	0	0	3133.745	0	0	0	0
SCTG39	0	0	0	0	711.9008	0	0	0	0
SCTG40	0	0	0	0	1088.497	0	0	0	0
SCTG41	0	0	0	1.052104	29.10704	0	0	0	8.608894
SCTG43	0.06671	0.041744	0	1.37E-05	0.84238	0.041744	0	0	0.007408
SCTG99	0.06671	0.041744	0	1.37E-05	0.84238	0.041744	0	0	0.007408

Table B-5 shows this reference in the opposite direction, indicating which industry consumes which commodities.

***Table B-5**: Use Coefficients by Industry and Commodity*

Commodity	Agriculture	Construction	Health	Leisure	Manufacturing	Mining	Retail	Wholesale	Service
SCTG01	166.435	8.623	1.006	0.576	11.188	8.623	26.532	26.532	87.325
SCTG02	2.810	7.737	0.583	0.110	8.045	7.737	6.805	6.805	28.851
SCTG03	107.551	182.070	8.192	3.078	105.791	182.070	127.262	127.262	291.450
SCTG04	6.897	4.603	0.353	0.796	17.855	4.603	12.377	12.377	38.949
SCTG05	190.286	8.577	9.624	3.631	60.307	8.577	43.047	43.047	74.914
SCTG06	27.336	3.295	0.003	6.097	57.220	3.295	103.089	103.089	181.644
SCTG07	854.169	16.416	0.240	17.500	727.346	16.416	406.972	406.972	574.950
SCTG08	44.799	1.365	0.018	1.568	104.258	1.365	80.459	80.459	113.579
SCTG09	0	0	0	0	1	0	0	0	0
SCTG10	0.324	0.432	0	0.216	1.807	0.432	9.840	9.840	20.447
SCTG11	0.052	0.034	0	0.025	0.367	0.034	1.138	1.138	2.850
SCTG12	0.292	0.193	0	0.142	2.082	0.193	6.446	6.446	16.150
SCTG13	0.210	0.119	0	0.100	1.519	0.119	5.224	5.224	11.377
SCTG14	0.089	0.271	0	0.006	0.770	0.271	1.391	1.391	1.881
SCTG15	0	0	0	0	1	0	0	0	0
SCTG16	0	14.709	0.001	0.021	5.266	14.709	4.810	4.810	40.067
SCTG17	0	4.504	0.001	0.062	0.214	4.504	0.587	0.587	0.684
SCTG18	0	4.504	0.001	0.062	0.214	4.504	0.587	0.587	0.684
SCTG19	0	19.706	0.002	0.292	10.691	19.706	9.784	9.784	47.663
SCTG20	5.555	6.648	0.003	2.795	124.747	6.648	69.714	69.714	98.951
SCTG21	0.007	0.927	0.003	0.446	54.918	0.927	21.135	21.135	85.901
SCTG22	0	1.962	0	0.427	23.736	1.962	34.287	34.287	21.988
SCTG23	0	2.086	0.004	2.092	130.089	2.086	43.369	43.369	139.217
SCTG24	0	5.313	0.012	10.806	170.388	5.313	71.067	71.067	166.788
SCTG25	1.192	439.025	0.773	0.534	14.600	439.025	84.419	84.419	116.618
SCTG26	4.259	682.990	0.021	44.158	1013.975	682.990	364.036	364.036	492.067
SCTG27	0	13.153	0	0.753	24.780	13.153	14.936	14.936	18.074
SCTG28	0	130.718	0.022	12.418	262.769	130.718	273.317	273.317	271.229
SCTG29	0	3.585	0.421	18.980	63.615	3.585	74.467	74.467	354.167
SCTG30	1.170	1.011	0.001	4.451	44.320	1.011	41.063	41.063	103.563
SCTG31	0	9.376	0.005	8.515	79.061	9.376	117.192	117.192	138.139
SCTG32	0	25.823	0.009	7.868	107.547	25.823	231.599	231.599	225.025
SCTG33	0	13.984	0.020	20.462	189.055	13.984	170.017	170.017	414.986
SCTG34	0	6.001	0.019	16.051	206.897	6.001	139.227	139.227	329.660

SCTG35	0	26.945	0.128	24.231	1573.704	26.945	602.492	602.492	1576.753
SCTG36	0	9.136	0.003	4.341	487.881	9.136	316.719	316.719	294.676
SCTG37	0	1.969	0.012	5.082	149.155	1.969	61.745	61.745	159.730
SCTG38	0	4.902	0.036	19.310	353.619	4.902	111.608	111.608	418.334
SCTG39	0	1.783	0.006	5.501	103.988	1.783	36.846	36.846	84.256
SCTG40	0.547	1.445	0.007	6.542	64.723	1.445	42.580	42.580	122.633
SCTG41	0	0	0	0	0	0	0	0	1
SCTG43	0.054	0.064	0.001	0.010	0.244	0.064	0.144	0.144	0.275
SCTG99	0.054	0.064	0.001	0.010	0.244	0.064	0.144	0.144	0.275

The subsequent disaggregation from counties to zones within the MSTM study area follows the same methodology as the disaggregation from FAF zones to counties. As fewer employment categories are available at the MSTM SMZ level, make/use coefficients of Table B-4 and B-5 were aggregated from eleven to four employment categories. Equations 5, 6 and 7 were used accordingly for the disaggregation from counties to SMZ.

The disaggregated commodity flows in tons need to be transformed into truck trips. Depending on the commodity, a different amount of goods fit on a single truck. FAF^2 provides average payload factors for four different truck types (Battelle 2002: 29) that were used to calculate number of trucks based on tons of goods by commodity (Table B-6).

Table B-6: Average Payload Factors by Commodity

SCTG	Commodity	Provided by FAF^2	Assumptions	
		Payload (lbs)	SUT	MUT
SCTG01	Live animals and fish	24,492	17,144	66,128
SCTG02	Cereal grains	27,945	19,562	75,452
SCTG03	All other agricultural products	22,140	15,498	59,778
SCTG04	Animal feed or products of animal origin	22,967	16,077	62,011
SCTG05	Meat, seafood, and their preparation	30,691	21,484	82,866
SCTG06	Bakery and milled grains	11,831	8,282	31,944
SCTG07	All other prepared foodstuff	25,926	18,148	70,000
SCTG08	Alcoholic beverages	20,573	14,401	55,547
SCTG09	Tobacco products	25,168	17,618	67,954
SCTG10	Monumental or building stones	25,429	17,800	68,658

SCTG11	Natural sand	29,501	20,651	79,653
SCTG12	Gravel and crushed stones	30,840	21,588	83,268
SCTG13	All other nonmetallic minerals	29,101	20,371	78,573
SCTG14	Metallic ores and concentrates	39,464	27,625	106,553
SCTG15	Coal	43,866	30,706	118,438
SCTG16	Crude petroleum	28,007	19,605	75,619
SCTG17	Gasoline and aviation turbine	48,686	34,080	131,452
SCTG18	Fuel oils	23,442	16,409	63,293
SCTG19	All other coal and refined petroleum	18,608	13,026	50,242
SCTG20	Basic chemicals	29,391	20,574	79,356
SCTG21	Pharmaceutical products	10,260	7,182	27,702
SCTG22	Fertilizers and fertilizer materials	19,833	13,883	53,549
SCTG23	All other chemical products	24,432	17,102	65,966
SCTG24	Plastic and rubber	19,324	13,527	52,175
SCTG25	Logs and other wood in rough	35,073	24,551	94,697
SCTG26	Wood products	18,494	12,946	49,934
SCTG27	Pulp, newsprint, paper, or paperboard	33,046	23,132	89,224
SCTG28	Paper and paperboard articles	26,282	18,397	70,961
SCTG29	Printed products	11,024	7,717	29,765
SCTG30	Textile, leather, and related article	20,608	14,426	55,642
SCTG31	Non-metallic mineral products	31,044	21,731	83,819
SCTG32	Base metal in finished or semi-finished form	24,458	17,121	66,037
SCTG33	Articles of base metal	14,395	10,077	38,867
SCTG34	Non-powered tools	6,064	4,245	16,373
SCTG34	Powered tools	10,698	7,489	28,885
SCTG34	Machinery	26,072	18,250	70,394
SCTG35	Electronic and other electrical equipment	13,821	9,675	37,317
SCTG36	Vehicle, including parts	15,690	10,983	42,363
SCTG37	All other transportation equipment	34,282	23,997	92,561
SCTG38	Precision instruments and apparatus	9,024	6,317	24,365

SCTG39	Furniture, mattresses, lamps, etc.	14,103	9,872	38,078
SCTG40	Miscellaneous manufactured products	16,462	11,523	44,447
SCTG41	Hazardous waste	29,113	20,379	78,605
SCTG41	All other waste and scrap	16,902	11,831	45,635
SCTG41	Recyclable products	18,859	13,201	50,919
SCTG42	Products not classified, not reported or applicable	21,739	15,217	58,695
SCTG43	Mail and courier parcels	11,826	8,278	31,930
SCTG43	Empty shipping containers	19,129	13,390	51,648
SCTG43	Passengers	2,613	1,829	7,055
SCTG43	Mixed freight	33,268	23,288	89,824
SCTG43	Multiple categories	14,621	10,235	39,477

Unfortunately, FAF payload factors are only provided for an average truck, while this model distinguishes single-unit und multi-unit trucks. In lack of true data, assumptions were made on the relative difference in payload factors for these two truck types. Based on analysis of payload factors by truck type[12], it was determined that a single-unit truck would carry 70% of the average payload factor and multi-unit trucks are assumed to carry 170% more than the average payload factor.

To split goods flows between single-unit and multi-unit trucks, the traveled distance is used as the explaining variable. This split is based on the assumption that single-unit trucks are more frequently used for short-distance trips, whereas multi-unit trucks dominate the long-distance market. The VIUS data were analyzed to extract the relationship between truck type and distance traveled. The VIUS attribute AXLE_CONFIG distinguishes 44 truck types, where ID 1 through ID 5 (straight trucks and truck tractors not pulling a trailer) were defined as single-unit trucks and ID 5 through ID 64 (straight trucks and truck tractors pulling a trailer) were defined as multi-unit trucks. The VIUS attribute TRIP_PRIMARY describes the trip distance this truck type is primarily used for. Table B-7 shows the data summary, where "Off Road", "Not reported" and "Not applicable" were not used in the model application.

[12]Based on table 3.2 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports7/c3_payload.htm

Table B-7: Truck Type by Primary Distance Class

Truck Type	Off Road	<= 50 miles	51-100 miles	101-200 miles	201-500 miles	>= 500 miles	Not reported	Not applicable
Single-Unit	1%	69%	9%	2%	1%	1%	14%	2%
Multi-Unit	3%	39%	14%	8%	9%	12%	15%	0%

Using the number of VIUS records, these data were converted into share of trucks in each distance bin, as shown in Table B-8.

Table B-8: Share of Truck Types by Distance Class

Distance in miles	SUT	MUT
0 - 50	82.4%	17.6%
51 - 100	63.3%	36.7%
101 - 200	44.0%	56.0%
201 - 500	26.8%	73.2%
> 500	16.9%	83.1%

The average payload factors and the share of truck type by distance class are combined to convert tons into truck trips.

$$SUT_{i,j} = \sum_{com} \frac{tons_{com,i,j}}{pl_{SUT,com} + \frac{shareMUT_{d_{i,j}}}{shareSUT_{d_{i,j}}} \cdot pl_{MUT,com}} \tag{9}$$

$$MUT_{i,j} = \sum_{com} \frac{tons_{com,i,j}}{\frac{shareSUT_{d_{i,j}}}{shareMUT_{d_{i,j}}} \cdot pl_{SUT,com} + pl_{MUT,com}} \tag{10}$$

where $SUT_{i,j}$ is the number of single-unit trucks from i to j

$MUT_{i,j}$ is the number of multi-unit trucks from i to j

$tons_{i,j,com}$ is the number of tons of this commodity going from i to j

$pl_{SUT,com}$ is the payload factor for SUT for commodity *com* given by Table B-6

$pl_{MUT,com}$ is the payload factor for MUT for commodity *com* given by Table B-6

$shareSUT_{d_{i,j}}$ is the share of SUT given for distance $d_{i,j}$ given by Table B-7

$shareMUT_{d_{i,j}}$ is the share of MUT given for distance $d_{i,j}$ given by Table B-7

Furthermore, an average empty-truck rate of 19.36 percent of all truck miles traveled (estimated based on U.S. Census Bureau data[13]) was assumed. As FAF provides commodity flows, empty trucks need to be added. Furthermore, the empty truck model takes into account that commodity flow data may be imbalanced. For example, to produce one ton of crude steel, 1.4 tons of iron ore, 0.8 tons of coal, 0.15 tons of limestone and 0.12 tons of recycled steel are commonly used[14], i.e. commodity flows into and out of such a plant are highly imbalanced. While it is reasonable to assume that commodity flows are imbalanced, trucks are assumed to always be balanced, i.e. the same number of trucks is assumed to enter and leave every zone in the long run. Figure B-4 shows a simplified example of flows between three zones. Blue arrows show truck flows based on commodity flows that are imbalanced, and red arrows show necessary empty truck trips to balance the number of trucks entering and leaving every zone.

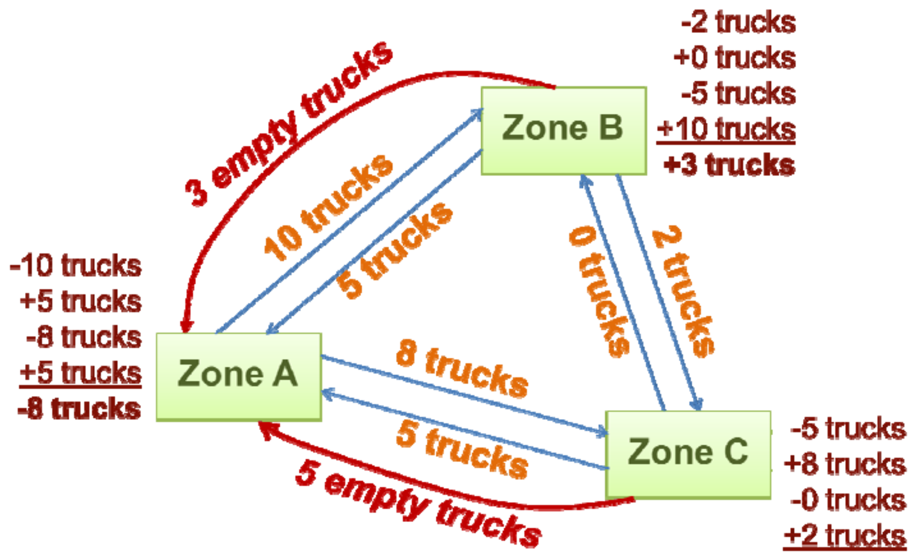


Figure B-4: *Example of Imbalanced Truck Flows (blue) That are Based on Commodity Flows and Required Empty Trucks (red)*

The concept of the truck model is shown in Figure B-5. All zones that have a positive balance of trucks (i.e. more trucks are entering than leaving the zone based on commodity flows) need to generate empty trucks, and their number of excess trucks are put into the empty truck trip matrix as row totals (purple cells in Figure B-5). Zones with a negative balance (i.e. more trucks are leaving than entering the zone based on commodity flows)

[13]http://www.census.gov/svsd/www/sas48-5.pdf

[14]http://worldsteel.org/dms/internetDocumentList/fact-sheets/Fact-sheet_Raw-materials2011/document/Fact%20sheet_Raw%20materials2011.pdf

need to attract empty truck trips, and their balance is put (as a positive number) as column totals into the empty truck trip matrix (yellow cells in Figure B-5).

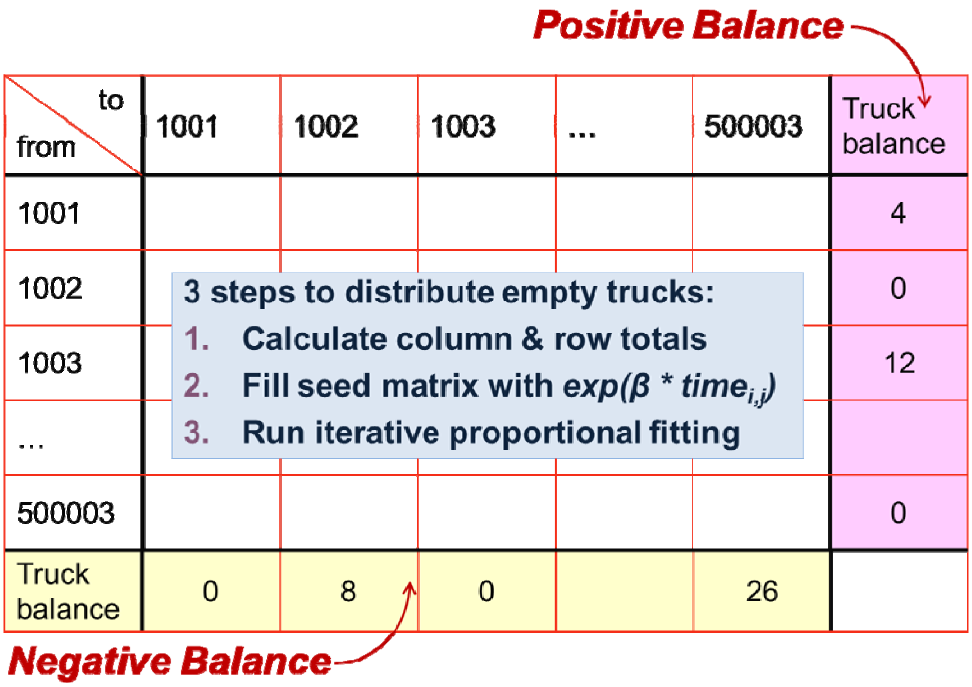


Figure B-5: Matrix of Empty Truck Trips

The cells within the empty truck trip matrix are filled with an impedance value calculated by a gravity model. It is assumed that empty trucks attempt to pick up another shipment in a zone close by, thus the travel time is used to calculate the impedance:

$$friction_{i,j} = \exp\left(\beta \cdot \mathrm{d}_{i,j}\right) \qquad (11)$$

where $friction_{i,j}$ is the friction for empty truck trips from zone i to zone j

β is the friction parameter, currently set to -0.1

$d_{i,j}$ is the distance from zone i to zone j

A matrix balancing process is used to distribute empty truck trips across the empty truck trip matrix. Empty trucks are balanced separately for single-unit and multi-unit trucks. These empty trucks are added to the truck trip table of loaded trucks. The first and the second row in Table B-9 shows the number of trucks generated based on commodity flows and the number of trucks generated to balance flows into and out of every zone. The number of empty truck trips necessary to balance truck trips by zone is significantly lower than the 19.36 percent empty trucks according the U.S. census bureau. Thus, another 17.2 percent of empty trucks needs to be added to account for the larger number of observed empty truck trips. These additional empty truck trips are added globally, i.e. all truck trips are scaled up to match the observed empty truck trip rate.

Table B-9: Number of Trucks Generated Based on Commodity Flows, Balancing Empty Trucks and Observed Empty Trucks

Purpose	SUT	MUT	Share
Trucks based on commodity flows (FAF3)	348,940	1,146,330	80.6%
Trucks returning empty for balancing	9,512	31,103	2.2%
Additional empty truck trips (Census data)	74,295	244,073	17.2%
Total trucks trips	432,747	1,421,506	100.0%

This is an interesting finding by itself. If all trucking companies were perfectly organized and cooperated on the distribution of shipments between trucks that are available close by, only 2.3 percent empty truck trips would be necessary. But because there is competition between trucking companies and because of imperfect information about available shipments, a much higher empty truck rate is observed in reality. Granted, this is a simplified empty-truck model, and the 2.3 percent empty-truck rate may not be achievable for two reasons: First, the model works with fractional numbers, i.e. the model may send 0.5 trucks from zone a to zone b, which is acceptable as the model simulates an average day but not possible in reality. Secondly, only two truck types are distinguished. It might be considered in future phases of this project to explicitly handle truck types, such as flatbed, livestock or reefer trucks.

Finally, yearly trucks need to be converted into daily trucks to represent an average weekday. As there are slightly more trucks traveling on weekdays than on weekends, a weekday conversion factor needs to be added.

$$trucks_{daily} = \frac{trucks_{yearly}}{365.25} \cdot \frac{AAWDT}{AADT} \qquad (12)$$

where $trucks_{daily}$ is the number of daily truck trips

$trucks_{yearly}$ is the number of yearly truck trips

$AAWDT$ is the average annual weekday truck count

$AADT$ is the average annual daily truck count

Based on ATR (Automatic Traffic Recorder) truck count data the ratio $AAWDT/AADT$ was estimated to be 1.02159, meaning that the average weekday has just 2 percent more traffic than the average weekend day. The resulting truck trip table with two truck types, single-unit and multi-unit trucks, is added to the multi-class assignment.

Regional Truck Model Data

The FAF data is provided in four different data sets.

- **Domestic**: Commodity flows between domestic origins and destinations in short tons.
- **Border**: Commodity flows by land from Canada and Mexico via ports of entry on the U.S. border to domestic destinations and from the U.S. via ports of exit on the U.S. border to Canada and Mexico in short tons.
- **Sea**: Commodity flows by water from overseas origins via ports of entry to domestic destinations and from domestic origins via ports of exit to overseas destinations in short tons.
- **Air**: Commodity flows by air from abroad origins via airports of entry to domestic destinations and from domestic origins via airports of exit to abroad destinations in short tons.

The FAF data contains different modes and mode combinations. For the purpose at hand, only the mode 'Truck' was used. Figure B-6 shows data included and excluded in this analysis. Combinations such as 'Truck & Rail' or 'Air & Truck' were omitted assuming that the longer part of that trip is done by Rail or Air, respectively, and only a small portion is done by truck. As the data does not allow distinguishing which part of the trip has been made by which mode, combined modes were disregarded for this study. 'Air & Truck (International)' was included as these allow extrapolating the portion from the international airport to the domestic destination, and vice versa, done by truck. Of the 200,320 flows that are omitted, only a very small portion of these trips is done by truck. The error is assumed to be fairly small. Border data were considered with the portion from the border crossing to the domestic destination or from the domestic origin to the border crossing. Likewise, sea and air freight was included as a trip from or to the domestic port or airport.

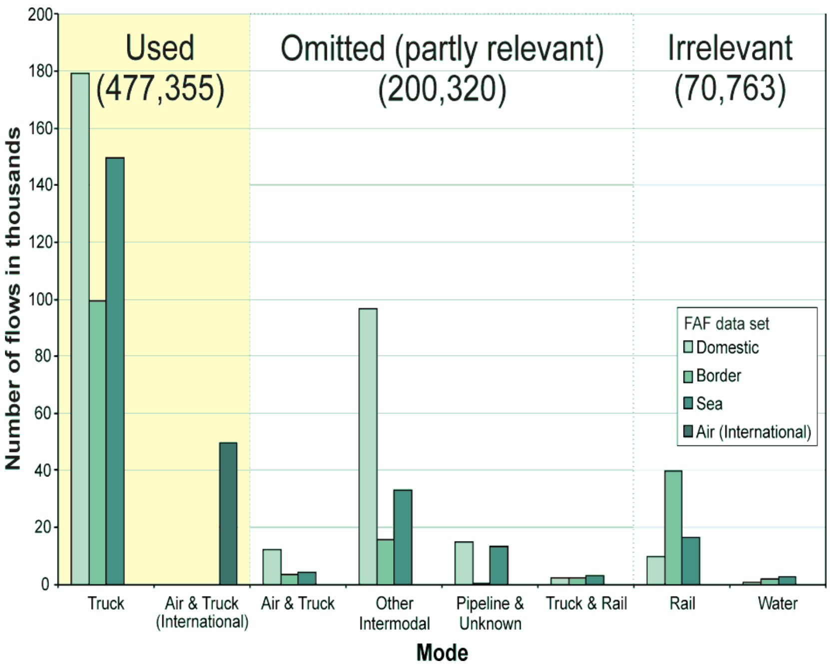


Figure B-6: Included and Excluded Data for the Analysis

A daily capacity of every highway link had to be estimated. In lack of true data the capacity was estimated based on the highway class and the number of lanes. While Interstate highways (both Urban Interstate and Rural Interstate) are assumed to have a capacity of 2,400 vehicles per hour per lane (vphpl), all other highways are assumed to have a capacity of 1,700 vehicles per hour per lane. The daily capacity is assumed to be ten times higher than the hourly capacity, as most transportation demand arises during daylight hours. To transform Annual Average Daily Traffic (AADT) into Annual Average Weekday Traffic (AAWDT) a factor of 265 working days was assumed.

Since trucks are not the only vehicles on the streets, autos need to be added as background volume on the highway network. In rural areas, a Level of Service (LOS) C is assumed, with a corresponding volume-to-capacity (V/C) ratio of 0.6 filled by cars. This is assigned to highways classified as "Rural Interstate", "Rural Major Collector", "Rural Minor Arterial", "Rural Minor Collector", "Rural Principal Arterial" or "Unknown". In urban areas, highways are assumed to be more congested, and the highway is expected to operate between LOS D and E, using a V/C ratio of 0.9 that is filled by cars.

Model Validation

The truck model was originally developed by Bill Allen for BMC and MWCOG. It made heavy use of geographically specific k-factors, which were all removed in the MSTM application. As a rigorous validation of the BMC or MWCOG truck model was never published, it is unknown how well the model performed when all k-factors were included.

For commercial vehicles and trucks, no survey data were available. Instead, data reported in the BMC and MWCOG reports were used to estimate the reasonability of the MSTM model output. The bright red bars show the model output of MSTM in phase 1, and the dark red show recalibrated the model output of phase 2 (Figure B-7). Green bar show target data reported in the MWCOG truck model report, and salmon and blue colored bars show the model output of the BMC and MWCOG models. It should be cautioned to consider the reported trip length of the BMC and MWCOG models as target data, as no observed data exists. Overall, the longer trip lengths may be due to the larger study area of MSTM. No further changes were made to the commercial vehicle and truck models in phase 3.

The current truck model is based on the BMC truck model, which mostly uses parameters of the FHWA Quick Response Freight Manual (QRFM). Those parameters were developed from a truck survey for Phoenix in 1992. These parameters are not only outdated but also originate from an urban form that is very different to Maryland. For future model updates, it would be desirable to conduct a truck survey to improve these modules by using local and recent data.

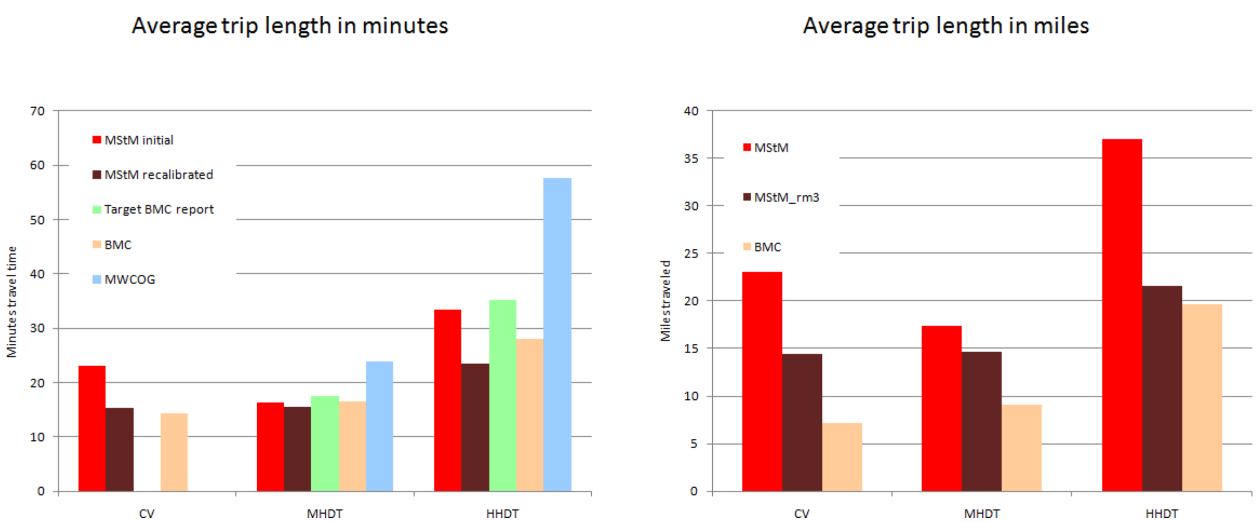


Figure B-7: Comparison of average trip length in survey and model results for CV and trucks

Figure B-8 shows the percent root mean square error for five different volume classes. It is common that the simulation of trucks does not perform as well as the simulation of autos. There is too much heterogeneity in truck travel behavior, and a large number of trips are not A-to-B and B-to-A trips but rather tours from A-to-B-to-C-to…to-Z, which are particularly difficult to model in trip-based approaches. Furthermore, there is no truck survey that was used to estimate truck trip rates. The rates applied are borrowed from the BMC truck model, which in turn copied and slightly modified these rates from the Phoenix truck survey from 1992. The person travel demand model, in contrast, uses a local survey for the BMC/MWCOG region from 2007, and thus, provides local recent data to calculate trip rates.

In light of these general difficulties in truck modeling, the MSTM truck model performs reasonably well. While the midrange from 500 to 5,000 observed truck trips results in a %RMSE of just over 100%, the highest volume range (>=5,000 observed trucks) with 337 truck counts achieves a fairly good %RMSE (by truck modeling standards) of 52%. It is expected that future phases could improve the truck model quite a bit a conducting a local truck survey and by splitting the four employment types currently used in MSTM into a larger number of types (such as ten employment types).

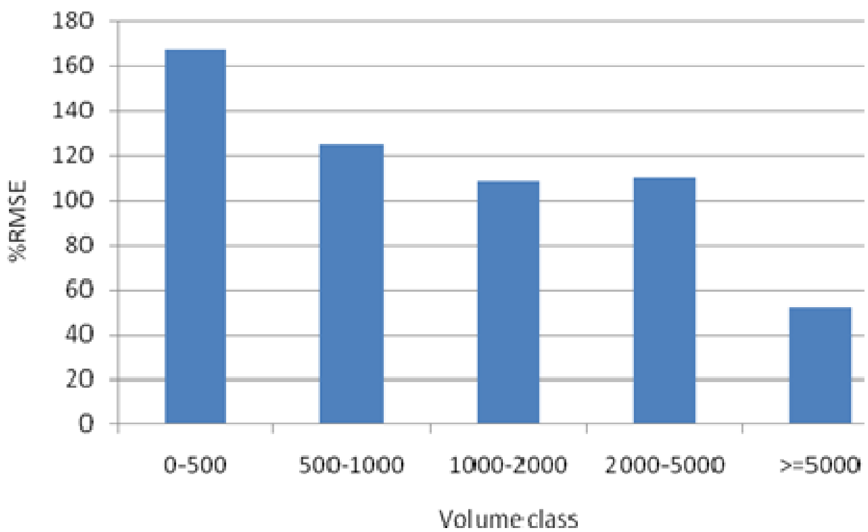


Figure B-8: Truck Percent Root Mean Square Error (%RMSE) by Volume Class