Multi Entity Perspective Freight Demand Modeling Technique: Varying Objectives and Outcomes

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ABSTRACT

The importance of freight transportation modeling and forecasting to better address planning issues is well recognized by policy makers. Compared to advancement in travel demand modeling for passenger travel, however, current freight demand modeling methods are not yet in the adequate levels to assess increasingly complex and important planning and policy issues. Three most important players in freight demand modeling are (a) shippers, (b) planners, and (c) policy (decision) makers who have different objectives. Past research is limited in proposing a unified methodology to address the objective of each player and to assess performance of transportation networks under conditions to achieve such objectives.

In this paper, freight demand modeling is designed to address each objective of the three players in a multimodal transportation network. A freight transportation model that combines three geographic scales—national, state, and local—is proposed and developed to capture different characteristics of short- and long-distance freight flows with a focus on state-level modeling in Maryland. Data for the model include freight flows by commodity and by Freight Analysis Framework (FAF) zones, which are further disaggregated to Statewide Modeling Zones in Maryland; a transportation network with detailed link level attributes; user costs in addition to all details needed for the travel demand model. In the modeling framework autos are simulated simultaneously with trucks in a multi-class user equilibrium traffic assignment. The results demonstrate the network performance and key information on travel characteristics for each player. The proposed tool can be used for freight travel demand modeling for analyzing impacts of policies at state, county and local levels.

Key Words: freight demand modeling, freight analysis framework, freight planning, multi-modal transportation modeling

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1. INTRODUCTION

In recent years, concerns with traffic congestion, energy consumption, and green house gasses are increasingly garnering attentions in United States (US) major metropolitan areas. According to the Texas Transportation Institute (TTI), commuters in 439 US urban areas are spending extra 4.8 billion hours or 34 hours per driver in each year, and wasting 3.9 billion gallons of fuel due to congestion (TTI, 2011). In addition, $23 billion of the total delay cost ($101 billion) was the adverse effect of congestion on truck operations without including any value for the goods transported by trucks. Since traffic congestion is an inevitable by-product of a vibrant economy, it is important to cope with it in an effective way in order to make an urban transportation system work efficiently. In particular, Moving Ahead for Progress in the 21st Century (MAP-21) explicitly recognized freight transportation is vital to economic growth. In the past similar transportation authorization, the Transportation Equity Act of the 21st Century (TEA) called for an increase in accessibility and mobility options and enhancing integration and connectivity of the transportation system for freight transportation as well as for passenger travel (FHWA, 1998; Pendyala et al. 2000). Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) allocated funding of over $4.6 million per year over three years to improve research, training, and education specifically for freight transportation planning (FHWA, 2005).

Transportation modeling and forecasting has an important role to address in planning and policy issues, ranging from general and long-range planning and project prioritization to modal diversion and economic assessment. Compared to significant advancements in travel demand modeling for passenger travel in the last four decades, however, current freight demand modeling methods are not yet at adequate levels to assess increasingly complex and important planning issues. The relatively slow progress in freight modeling is due to the evolving nature of behavioral theory and lack of publicly available data (Pendyala et al. 2000). Literature suggests that there are three primary stakeholders in the freight industry, who either influence freight transportation policy or get affected by freight policy changes. In addition, past research is very limited in proposing a unified methodology of freight demand modeling to assess performance of a transportation network, carefully taking into account objectives of three players—1) shippers, 2) planners, and 3) policy makers.

Each of these three players has a different objective that is geared towards attainment of self-centered goals. First, the objective of shippers is to transport goods from an origin to a destination at the lowest travel cost (which consists of travel time, distance, and toll). Shippers ideally like to make reliable trips free from congestion and accidents to ensure on-time product delivery to customers. The objective of planners is to design and plan for an efficient, safe, and reliable transportation system through demand management strategies. The objective of policy makers is to bring revenue-generating economic activities in their jurisdiction to enhance growth. The overall goal of these players are quite complex, but the objectives are simplified for an quantitative analysis from a freight demand modeling perspective as discussed in this paper.

The objective of the paper is to examine the network performance and freight travel behavior at national, state and local levels when different goals are considered from shippers, planners, and policy makers. The scope includes:

- Methodology of long distance truck travel demand model
- Scenarios on objectives of shippers, planners, and policy makers
- Application of the methodology in a real world case study

In this paper, in order to clearly account for the objectives of the three important players, a freight transportation model is designed and applied to capture different characteristics of short- and long-distance freight flows in a multimodal transportation network, combining three geographic scales—national, state, and local—with a focus on long-distance truck trips at the state level. These freight flows are modeled in network conditions that vary by time of day and also in uncertain market conditions in which freight demand can vary by each of the three objectives. The proposed model is evaluated in terms of vehicle miles travelled (VMT), congested lane miles (CLM), and vehicle hours of delay (VHD) at different levels of geography, including (1) statewide level, (2) facility type level, and (3) corridor level in Maryland.

This paper is structured as follows. The next section provides a brief literature review of freight demand modeling with a focus on a state-level modeling, followed by sections to describe research objectives, methodology, and data sources. Then details of analysis results and discussion are presented, and the paper concludes with future research agendas.

2. LITERATURE REVIEW

The literature review is organized into three parts: (1) entities involved in freight planning, (2) challenges in freight travel demand modeling, and (3) performance measures used in freight planning.

2.1. Entities involved in freight planning

Freight transportation has a number of properties that makes it difficult to directly apply in passenger demand models (Pendyala, 2000). Many different factors certainly influence freight flows, including commodities transported and various players involved in the freight transportation process. Given many different industries that generate truck traffic and different commodities transported, the heterogeneity of freight flows is much larger than person travel. In addition to truck operators, players outside the trucking industry have substantial stakes on how freight transportation works. First, freight trips are derived from the demand of shippers to transport goods from one place to another within a certain time limit. Second, transportation planners manage highway systems for an efficient, safe and reliable transportation system through various demand management strategies. Third, decision makers' policy decisions to bring in economic activities influence freight demand and movement on the roadway system.

The statewide study by New Jersey Department of Transportation (NJDOT 2007, p.47) took into account different perspectives of stakeholders of freight planning in the private sector (shippers and freight operators in truck, rail, air, and maritime industries) and the public sector (departments of transportation, metropolitan planning organizations, regional port organizations, and municipal, county, and state governments). The considerations based on the survey were categorized into four areas: (1) congestion related, (2) costs associated with inefficiencies in the freight delivery system, (3) operation and coordination of the system, and (4) regulatory issues at the local and state levels. It remains unresolved how these outcomes can be incorporated in a travel demand modeling context. A study in Sweden by Behrends et al. (2008) identified city administrators, shippers, and planners as critical players in freight planning and their main objectives. While the objective of city administrators was to improve land use planning and prevent urban sprawl, shippers and planners were interested in reduction of traffic congestion and better mode split, respectively. Although these studies qualitatively discuss the importance of multiple stakeholders, neither developed a methodology to incorporate their substantial influences in planning, operations, and usage of transportation infrastructure systems.

2.2. Challenges in freight travel demand modeling

While freight can take long distance trips, a significant portion of freight trips are made at the state level. The 2007 Commodity Flow Survey reported that 33 percent ($3.9 million) of the value and 54 percent (7.1 billion tons) of the weight of all shipments were transported for distances less than 50 miles (Bureau of Transportation Statistics, 2007). Thus, the development of a robust statewide freight transportation model is essential for planning and policy decision making. It is also very important for planning purposes to develop statewide freight transportation models capable of incorporating: (1) factors that directly influence the demand of commodities (such as macro economic factors and socio-economic demographics), and (2) factors that indirectly affect the demand through changing the cost and level-of-service of freight transportation services (such as freight logistics, transportation infrastructure, government policies, and technologies) (Cambridge Systematics, Inc., 1997; Pendyala et al. 2000). A recent National Cooperative Freight Research Program (NCFRP) study reviewed the freight demand modeling techniques currently available in the field for decision making for both public and private sectors (NCFRP 2010). The NCFRP report suggests that lack of modeling techniques prohibits accurately estimating performance measure, particularly for public sector agencies.

Since the 1980s, most freight demand models applied in practice have employed an aggregated analysis based on traditional trip-based person travel demand model, which involves following three major steps: (1) freight generations and attractions by zone, using trip rates by vehicle type and industry classification, (2) distribution of freight trips or volumes to meet demands at trip destinations, and (3) route assignments of origin-destination trips (Kim and

Hinkel, 1982; Pendyala et al.2000). Substantial progress was made in the US in the development of statewide intermodal management systems, including freight transportation, because of the provisions of ISTEA (Samadi and Maze 1996), and later by SAFETEA-LU and MAP-21.

Researchers and practitioners have been attempting to model freight travel in various geographic contexts for multifaceted planning purposes. Some consider freight planning for a city; others focus on a county, state or region. Depending on geographic scales, various planning techniques have been proposed in the literature. Hunt and Stefan (2007) proposed a tour-based microsimulation model for urban commercial movements in Calgary, Canada. But the model was designed for commercial vehicles only in urban areas and did not consider implications at the regional scale and also ignored heavy trucks. Oum (1979) proposed a cross-sectional study of freight demand and rail-truck competition in Canada, which did not include route choice interaction and may have limited use in freight planning. Chiang et al. (1981) developed a framework for a freight-demand model that involved the choice of mode as well as shipment size. However, this model may not be very useful for planning agencies because of the absence of interactions between freight modes and networks. Crainic et al. (2009) explored the possibility of developing intelligent freight transportation systems that the authors suggest are useful to commercial vehicle operators and logistics business. This study indicated potential of operation research in freight planning with available techniques, but did not suggest how travel behavior of freight shipments can be considered. Holguin-Veras (2000) provided a framework for an integrated freight market simulation that assigns freight origin-destination demand to a transportation network using real time traffic control devices. Unavailability of firm, commodity, and shipment specific data, however, makes this framework unfeasible to apply at a large scale. Harris and Liu (1998) recommended the use of a hybrid input-output table to analyze freight demand, but did not provide demand functions and ignored congestion effects. While Culliane and Toy (2000) identified variables influential to freight mode and route choice decisions, they did not provide a modeling context related to travel behavior. Garrido and Mahamassani (2000) proposed a firm specific freight transportation demand model and highlighted the complexities involved in developing a large model for all firms in a region.

Forecasting Statewide Freight Toolkit, a report by National Academy of Sciences, suggests that ideally freight planning should be conducted using commodity, origin, destination, mode, route, and time steps, which are often not followed or partially omitted in freight planning (NCHRP 2006). Because some freight data are unavailable, an assumption is made to use ad-hoc variables, such as employment, in a number of steps in freight trip generation. Trip distribution is carried out with a gravity model that uses distance and/or time as a travel impedance variable. Due to data limitation and modeling difficulty, most freight models focus on truck movements and do not include mode choice, assignment, and time of day distribution (Proussaloglou et al. 2003). Therefore, trucks are usually the only mode considered in the final trip assignment stage (NCHRP, 2006).

2.3. Performance measures used in freight planning

Freight performance measures are in high need for state and local agencies to evaluate freight performance in the existing transportation system (Southworth, Lee, Griffin, and Zavattero, 1983). With the surface transportation reauthorization MAP-21, new incentives have been provided for state DOTs to integrate performance measures into their transportation planning and operations. A national study enumerates that performance measures, such as vehicle miles travelled, delay, travel time reliability, or bottleneck segments, are considered by public agencies for evaluation of the freight transportation system (NCFRP 2011). However, lack of data and analytical tools have been preventing DOTs from developing such freight performance measures within modeling tools.

The literature review indicates that a careful examination of network performance and freight travel behavior requires substantial progress in terms of: 1) incorporating different objectives in freight transportation for the three main players—shippers, planners, and policy makers and 2) connecting different geographic scales—national, state and local—in one freight transportation model. It should be noted that some scholars are very critical about the application of the four-step model, as the model is developed for passenger travel and is inherently different from freight transportation (Meyer, 2008). Meyer (2008) suggests that freight modeling requires more than one type of model—microsimulation, econometrics, hybrids—from multiple disciplines (such as regional economics, industrial engineering, civil engineering, urban geography, and businesses) to capture different aspects of freight transportation, including logistics, supply chain, and network flows.

3. METHODOLOGY

This section is organized in four parts. First, the methodology of a long distance model is presented. Second, data used in this study are described. Third, the study area and input data are explained. Fourth, details of scenarios in which each group of shippers, planners, and policy makers pursue their own self-centered objectives are discussed.

Long-distance truck trips are generated by commodity flow data given by the Federal Highway Administration of the U.S. Department of Transportation in the Freight Analysis Framework (FAF). The FAF^3 (version 3, the terms FAF^3 and FAF are used interchangeably in the paper) data contain flows between 130 domestic FAF zones and 8 international FAF zones.. The subject case in this paper is state of Maryland, US. Maryland is subdivided into three FAF zones (Figure 1): the Baltimore region, the surrounding region of Washington DC in Maryland, and the remainder of Maryland. In some cases, a single FAF zone covers an entire state, such as Maine, Mississippi or Montana. Flows from and to these large state FAF zones appear as if everything is produced and consumed in one location in the state's center (or the polygon centroid).

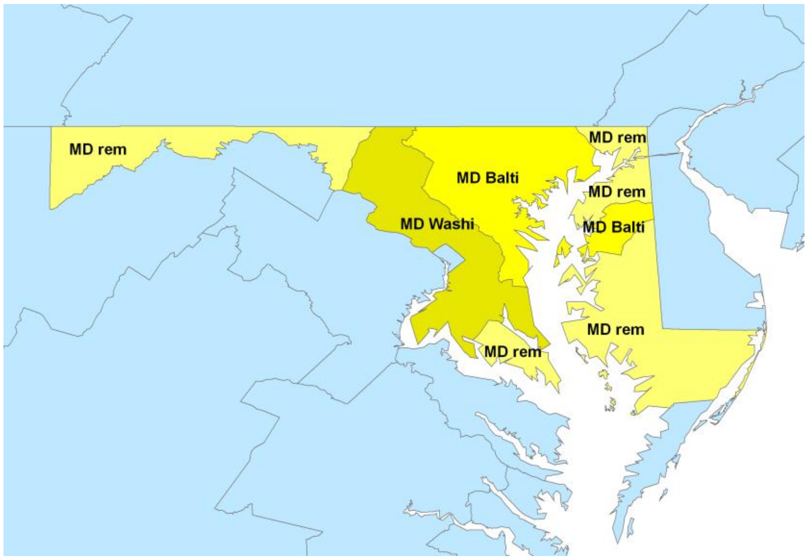

Figure 1: FAF zones in Maryland

To achieve a finer spatial resolution, truck trips are disaggregated from flows between FAF zones to flows between counties based on employment distributions (Battelle 2002). Four employment types are considered from the Bureau of Economic Analysis: retail, office, industrial, and others. Subsequently, trips are further disaggregated to state modeling zones (SMZ) in the statewide model areas or aggregated to regional modeling zones (RMZ) outside the statewide model areas (Figure 2).

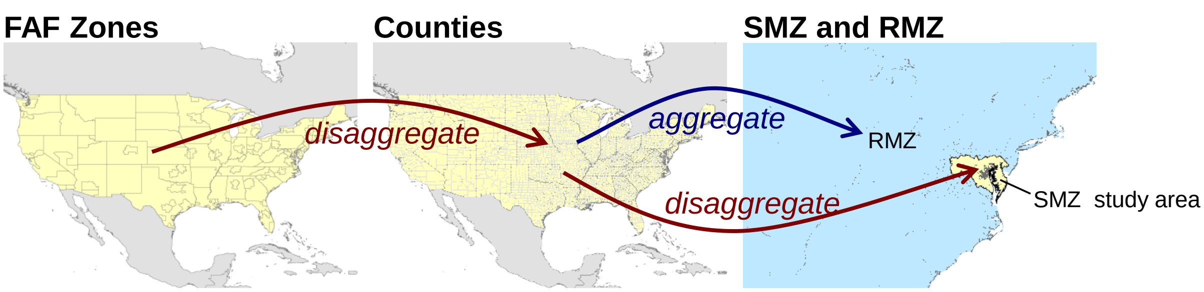

Figure 2: Disaggregation and aggregation of freight flows

Table 1 provides details of these disaggregations in the Maryland Statewide Transportation Model (MSTM) that is used as a tool to analyze the proposed framework. In the first step (step 1a), most areas outside Maryland use total employment to disaggregate commodity flows from each FAF zone to all counties within this FAF zone. In contrast, Maryland uses county employment data by 21 industries to disaggregate FAF zones to counties (step 1b). The information of these industries ensures consistency between employment and commodity flows to improve the quality/accuracy in disaggregating flows that enter and depart Maryland. For example, crops are generated in counties with a higher employment share in agriculture; raw metal is transported to counties with a higher employment share in manufacturing. The second level of disaggregation from counties to SMZ within the statewide model area uses four types of employment (Industrial, Retail, Office and Other) provided by a number of local metropolitan planning organizations (MPOs) (step 2).

Table 1: Three types of disaggregation applied in MSTM

Step	From	To	Based on
1a	FAF zones	Counties (outside Maryland)	Total employment
1b	FAF zones	Counties (inside Maryland)	21 employment categories
2	Counties	SMZ	4 employment categories

In step 1a in Table 1, the disaggregation process uses total county employment as weights to split commodity flows from one FAF zone to all counties within this FAF zone. The same methodology is applied for disaggregation within the destination FAF zone; the more employment a county has, the higher the share of commodity flows this county receives, compared to all other counties in this FAF zone. The following equation shows the calculation to disaggregate a flow from the FAF zone to the country level; a flow from FAF zone *a* to FAF zone *b* is converted to multiple flows from county *i* located in FAF zone *a* to county *j* located in FAF zone *b*.

$$flow_{county_i, county_j} = flow_{FAF_a, FAF_b} \cdot \frac{weight_{county_i, county_j}}{\sum_{county_k \in FAF_a} \left(\sum_{county_l \in FAF_b} weight_{county_k, county_l} \right)}$$

where $county_i$ is located in FAF_a

$county_j$ is located in FAF_b

$county_k$ are all counties located in FAF_a

$county_l$ are all counties located in FAF_b

The weights are identical for each commodity, and are calculated by the following equation:

$$weight_{county_i, county_j} = empl_i \cdot empl_j$$

where $empl_i$ is total employment in county *i*

In step 1b in Table 1, county employment in 21 categories and coefficients that are adapted from the Ohio Statewide Model are used to disaggregate flows from FAF zones to counties within Maryland (MSTM 2011). There are two kinds of coefficients[1]: "make" and "use" coefficients. The "make" coefficient represents level of production of goods related to each commodity, the "use" coefficient represents level of consumption. Different from step 1a, the weights for flows into and out of Maryland in step 1b are commodity-specific. These weights are calculated by the following equation:

$$weight_{county_i, county_j, com_c} = \sum_{ind_m} \left(empl_{county_i, ind_m} \cdot mc_{ind_m, com_c} \right) \cdot \sum_{ind_m} \left(empl_{county_j, ind_m} \cdot uc_{ind_m, com_c} \right)$$

where $empl_{county_i, ind_m}$ is the employment in county *i* in sector *m*

mc_{ind_m, com_c} is the "*make"* coefficient describing how many goods of commodity *c* are produced by industry m

uc_{ind_m, com_c} is the "*use"* coefficient describing how many goods of commodity *c* are consumed by industry *m*

In step 2 in Table 1, the same equations as in the disaggregation 1b are used. The only difference is that 21 employment types with the corresponding "*make/use*" coefficients are available and used for counties in Maryland, while only four employment types and the corresponding "*make/use*" coefficients are available at the SMZ level (MSTM 2011).

Goods' flows are converted into truck trips using average payload factors for four different truck types (Battelle 2002). Depending on the commodity of the good, a different amount of goods fit on a single truck on the average. The breakdown of trucks/trailers in four different sizes in the U.S. is shown in Table 2.

Table 2: The Breakdown of Trucks and Trailers by Size

Single Unit Trucks	Semi Trailer	Double Trailers	Triples
30.7 %	15.5 %	26.9 %	26.9 %

Source: U.S. Department of Commerce 2004: 43

[1] "Make" and "use" coefficients that reveal the mix of goods required to produce $1 of output or consumption, respectively, can be derived from the IO flows. These coefficients are typically used in lieu of the actual flows, as they scale to any level of production and consumption. Hewings (1985) and de la Barra (1989) both provide an excellent description of their typical derivation.

In addition, an average empty-truck rate of 20.8 percent of all truck miles traveled (estimated based on U.S. Census Bureau (2008)) is assumed and added to the estimated truck trips that are based on FAF goods' flows, using the following equation.

$$trk(all)_{i,j} = \frac{trk(loaded)_{i,j}}{(1-etr)}$$

with $trk(all)_{i,j}$ Trucks from zone i to zone j including empty trucks

$trk(loaded)_{i,j}$ Loaded trucks from zone i to zone j based on FAF2 data

etr Empty truck rate

In the next step, commodity flows between SMZs and RMZs are assigned to the highway network of the entire U.S. This model with 3,241 counties and 1,607 SMZ and 132 RMZ achieves the higher resolution than 130 FAF regions. In the procedure of converting these disaggregated goods' flows to truck trips, the second layer of this two-layer model design improves the accuracy in assigning truck trips to sub-regions based on the distinction of industry-specific employment within the SMZ area.

The route assignment stage of modeling requires a daily capacity of every highway link. Due to lack of comprehensive information, the road 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.

3.1 Regional Truck Model Data

This study uses the FAF data provided in four different data sets.

- **Domestic**: Commodity flows between domestic origins and destinations in short tons[2].
- **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.

[2] 1 short ton = 907.18474 kilograms; a United States unit of weight equivalent to 2000 pounds.

- **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 of this study, only the mode 'Truck' was used. Border data considers 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.

4. STUDY AREA AND POLICY IMPLEMENTATION

The MSTM is a multi-layer model working at a national, statewide and local level. This model is used for analyzing the impacts of different scenarios on the highway traffic in different scales. The model structure of MSTM is available in the literature (Mishra et al. 2013). The statewide study area consists of 64 counties including all of Maryland, Delaware, and Washington D.C. and portions of Pennsylvania, Virginia and West Virginia. A buffer around Maryland was added to better account for flows near the state's border. Figure 3(a) and 3(b) show maps of SMZs and RMZs respectively.

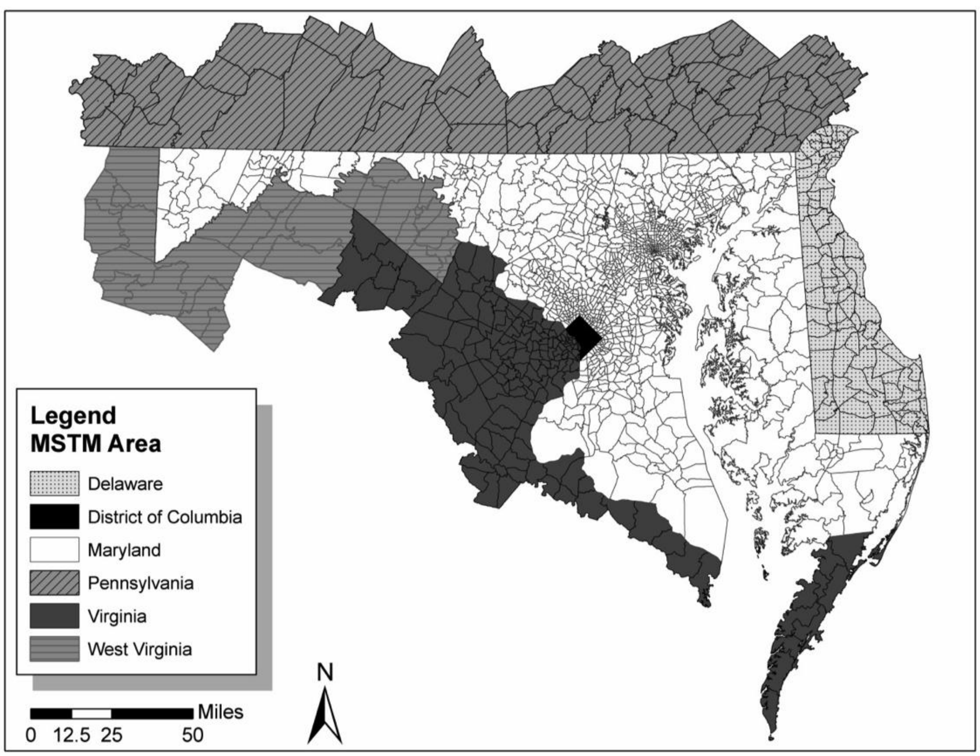

Figure 3(a): Statewide Modeling Zones in MSTM

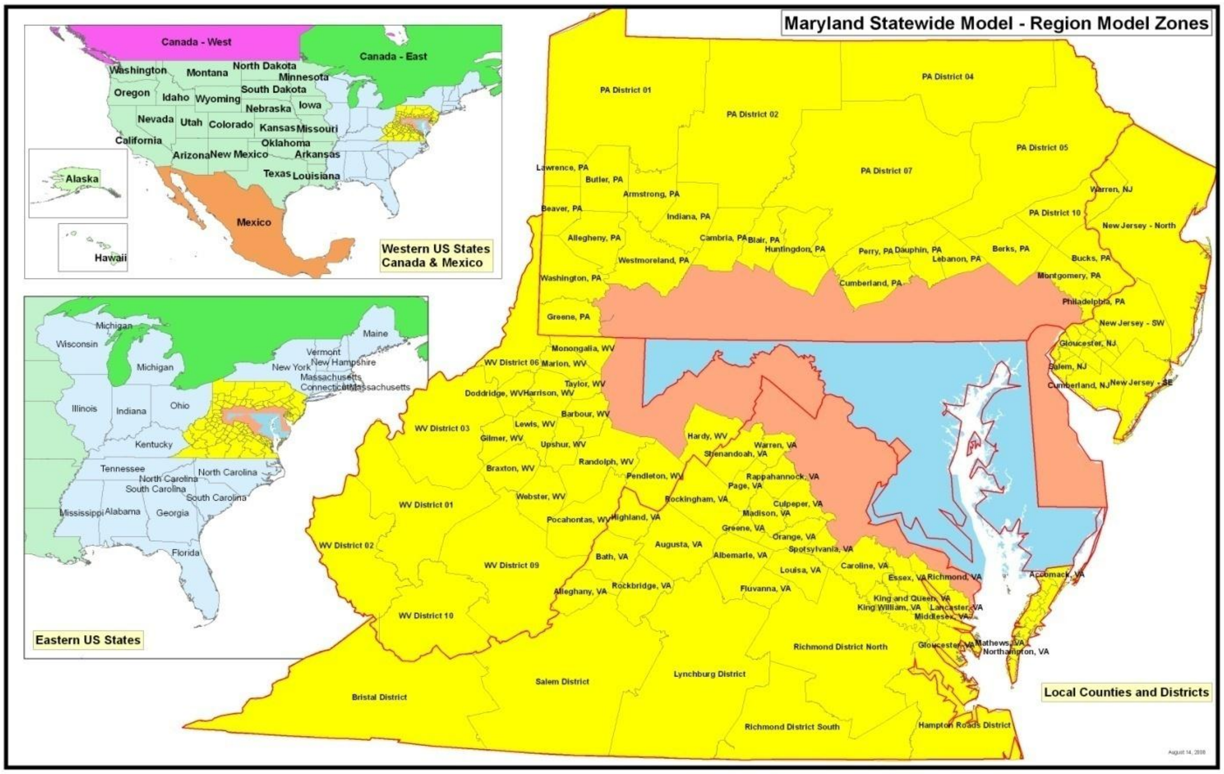

Figure 3(b): Regional Modeling Zones in MSTM

The true value of a comprehensive statewide model becomes apparent when policy scenarios are analyzed. For example, the model makes it possible to examine the impacts of freight infrastructure investments on traffic flows, the economy and the environment, prior to the actual implementation of proposed projects in reality. Table 3 shows three different policy scenarios tested with the MSTM to examine their likely impact on the transportation system, in addition to the base scenario that analyzes the business-as-usual case. The scenarios are based on the perspectives of the three types of stakeholders with different motivations, and aim at affecting truck flows and passenger vehicles.

Table 3: Policy Scenarios

Stakeholder's perspective	Objective	In MSTM
Shipper's	Congestion-free travel	Capacity of access controlled facilities is doubled
Planner's	Relief congestion and reduce emissions	A better transfer of commodities from highway to rail is obtained.
Policy Maker's	Economic Growth	Economic growth of Ports in the region is increased

While the proposed model is useful to analyze objectives of the three players, a number of assumptions are made to realistically implement and quantify them in a travel demand model. In reality, these objectives can be more complex than what is portrayed in the paper. The assumptions are described as follows.

- The objective of shippers is congestion free travel and to deliver products to customers on time. However, shippers are not concerned about the capital cost and effort needed to create a transportation infrastructure for congestion-free travel. The economic and political consequence of such a strategy is beyond scope of the paper. Because of new incentivized transportation infrastructure, the induced demand of travel is also not a concern for the shippers. The induced demand will not be captured in the scope of the proposed travel demand model either.
- The objective of planners is to alleviate congestion and reduce emissions by various travel demand management strategies. The effort required to achieve such demand management strategies is beyond the scope of the paper.
- The objective of decision maker's is to bring economic growth to the study area and one of the means is to enhance growth of ports. Increased capacity of ports will result in a wide range of impacts, such as increase in economic activity and redesign of port architecture to accommodate such growth, which are beyond the scope of this research.

The first stakeholder group is freight shippers. Trucking companies often criticize a lack of road infrastructure investment by the public administration, claiming that traffic congestion is exacerbated resulting in economic loss to the order of billions of dollars per year (NJDOT 2007). In this scenario, capacity of interstate highways is doubled in terms of the number of lanes from the base scenario, with an assumption that there are no budgetary and engineering constraints to widen the highway network. Certainly, this is not a realistic capacity increase to happen, as many governments struggle to provide even adequate road maintenance services and as many interstate highways in the MSTM region are located in densely populated areas with little space left to widen highways. Setting such practical issues aside, this scenario has been chosen to explore the validity of shipping companies' claim that the bottlenecks on the highway network should be addressed.

The second scenario reflects the planners' perspective. Regional and urban planners think that congestion and vehicle emissions are reduced more effectively by shifting freight transportation from trucks to rail (Donnelly 2007). Since many rail facilities operate at capacity within the MSTM study area (MSTM 2011, Mishra et al. 2014), it is likely that expanding rail capacity will increase shipments by rail. Thus, the scenario based on planners' perspective assumes doubling rail capacity, and it is assumed that this increased capacity is used by freight flows that travel by truck in the base case. Specifically, for every FAF zone origin-destination pair, the rail flows are doubled, and the tons added to the rail network are removed from the truck flows. It should be noted that an actual modal shift model is beyond the scope of this research. Rather, a rule-based approach has been chosen to understand the impact of shifting freight flows from truck to rail. An analysis based on this scenario improves an understanding of the likely effects of increasing rail freight capacity on road traffic conditions on the highway network.

The third scenario represents the viewpoint of policy makers, assuming that some policy makers promote a flagship project that would increase regional employment and stimulate a regional economy. The expansion of east coast ports has been discussed in the media, particularly because the widening of the Panama Canal will allow larger ships from Asia to access the East Coast states directly. Thus, in this scenario, the Port of Baltimore and the Port of Norfolk are assumed to grow in capacity. Specifically, the Port of Baltimore is assumed to expand by no more than 100 percent, because it is located fairly close to downtown Baltimore and does not have much space left to expand. On the other hand, the Port of Norfolk is assumed to grow by 200 percent. It should be noted that it is simply assumed that additional capacity would be filled up without an analysis of whether or not such demand to increase the flows through the Ports of Baltimore and Norfolk actually exists. Existing freight flows through the port are doubled; the same commodities and the same origin-destination pairs are used for the additional flows. The scenario does not include any change in employment at the ports, as increasing automation of technologies at ports has tended to reduce employment even under an increasing amount of goods shipped through ports (Musso et al. 2000). The scenario based on policy makers' perspective analyzes the impact of increased commodity flows, which go through the two ports and are transported by truck to final destinations in the MSTM region on the highway network.

5. RESULTS AND DISCUSSION

The proposed methodology of freight planning is analyzed by MSTM, which incorporates the objectives of the three different stakeholder groups—shippers, planners, and policy makers. In this section, the analysis results present the impacts of the different policies envisioned by these stakeholder groups on the transportation system in the following three geographic/physical levels: (1) at state level, (2) at facility type level, and (3) at corridor level. Three performance measures, namely VMT, CLM, and VHD, are computed at these three geographic levels. Results of the AM peak period are shown for brevity as other time periods also follow similar trend. Passenger travel is analyzed simultaneously with truck travel in the travel demand model analysis. For brevity, details of passenger travel are not discussed in this paper.

5.1 State Level Impact

5.1.1 Vehicle Miles Traveled

Table 4 shows the statewide total VMT for the base case and three policies for the AM perk period (6:30AM to 9:30AM). The differences between all three scenarios are relatively small, even though the scenario assumed a fairly dramatic change in the transportation infrastructure. Table 4 shows that VMT is the highest under shippers' perspective scenario among three scenarios, because increase in highway capacity makes highways, expressways, and freeways more attractive than the base case, resulting in higher traffic volume for these roadways. In other words, a mode shift from transit to highways on the passenger side is induced by the highway capacity increase to result in an increase in VMT under this scenario.

Table 4: State Level and Facility Type Impact Comparison of Various Performance Measures in AM Peak Period

	State Level Impact (Compared to Base Case %)			Facility Type Impact (Compared to Base Case %)		
Measure	Shipper's	Planner's	Policy Maker's	Shipper's	Planner's	Policy Maker's
VMT	0.61%	-0.18%	0.20%	5.33%	-0.34%	0.38%
CLM	-47.93%	-0.58%	0.59%	-97.72%	-1.55%	1.38%
VHD	-18.75%	-0.25%	0.25%	-54.52%	-0.45%	0.48%

VMT is the lowest under the planners' perspective scenario. This is because larger number of truck trips are diverted to rail and result in reduction in vehicle traffic and less congestion on highways, compared to the base case. This result shows a potentially preferable management of truck traffic without large capital investment in the highway system because of recent attentions toward intermodalism, sustainable transportation, and less dependence on oil. Lastly, the policy makers' scenario resulted in the higher VMT than the base case, because the levels of production and attraction of freight commodities increase while no capacity of transportation infrastructure is added. The observations for other time periods of the day are similar to the AM peak period. In short, irrespective of the time of day, the shippers' perspective scenario has the highest VMT, and the planners' perspective scenario has the lowest VMT.

5.1.2 Congested Lane Miles

Table 4 also shows the total statewide CLM that represents lane miles with volume to capacity ratio more than 0.8 (*i.e.*, level of service lower than E). The lower number of CLM represents a better operational condition. The lowest number of CLM is reached in the AM peak period under the shippers' perspective scenario because of the highway capacity expansion desired by the shippers. The highest CLM is observed under the policy makers' perspective scenario, because of an increase in freight travel demand with no increase in the highway capacity. The CLM under the planners' perspective scenario shows the congestion levels in the two other scenarios as the total freight travel demand remains the same as in the base case and it is managed by a better modal distribution.

5.1.3 Vehicle Hours of Delay

In terms of VHD, the policy makers' perspective scenario results in the highest VHD among all cases analyzed (Table 4), because the freight demand generated in the additional good movements at the ports increases freight traffic that is not accommodated adequately by the highway system without additional capacity. This port expansion causes more congestion and results in overall longer travel time. In contrast, the capacity expansion under the shippers' perspective scenario results in the least VHD as expected.

5.2 Facility Type Impact

Facility types represent highway functional classes such as freeway, interstates, expressway, major arterial, minor arterial, collector and local streets. The facility-type impact is examined at a more disaggregate level than the state level, using the same measures. Only interstate facility type impact is presented in Table 4. The three columns on the right side of Table 4 show the percentage increases in VMT, statewide total CLM, and VHD on the interstate highways in the AM peak period in the three different scenarios, compared to the base case scenario.

5.2.1 Vehicle Miles Travelled

As observed in statewide level results, VMT is the highest under the shippers' perspective scenario also for only interstate highways, because capacity expansion of interstate highways gives this facility type an advantage in terms of travel time. Trips from adjacent facility types and from other modes are attracted to highways, resulting in higher traffic volume. The least VMT is observed under the planners' perspective case as part of the freight trips are diverted to rail. The decision makers' perspective scenario shows slightly higher VMT than the base case because of increased demand to reflect economic growth without managing travel demand.

5.2.2 Congested Lane Miles

The obtained results for CLM are similar to the results for VMT. CLM is the smallest under the shippers' perspective scenario, because of its capacity expansions, combined with the similar demand level as in the base case. Among all scenarios, the policy makers' perspective scenario resulted in the highest CLM, followed by the planners' perspective.

5.2.3 Vehicle Hours of Delay

The shippers' perspective scenario has the lowest VHD in the AM peak period, because the highway capacity expansion under this scenario reduces travel time on interstates highways and results in less delay. The highest VHD occurs under the policy makers' perspective scenario. Under the planners' perspective scenario, VHD is between the other two cases.

5.3 Corridor (Link) Level Impact

Different from Table 4 discussed in the previous sections, Table 5 shows the impacts on daily traffic volume at the corridor level—the most disaggregated level among the three geographic/physical levels. Five bridge crossings are used as they are often considered to be critical facilities of the transportation system (Figure 4). The impact is measured in terms of the percent change in directional traffic volume in each scenario in comparison to the base case. The results in the shippers' perspective scenario show that all bridges carry substantially higher traffic volume, compared to the base case. As this perspective, is related to a capacity expansion of interstates and freeways, these roadways become more attractive, resulting in the higher traffic volume. Four of these bridge crossings are on an interstate highway, and traffic is diverted from local roads to highways after the capacity is increased. In contrast, under the planners' perspective, traffic volumes decline from the base case because of the mode shift from highway to rail. Also under the policy makers' scenario, traffic volumes at these bridge locations are higher than the base case, reflecting higher economic growth expected from an increased goods' flow through the ports without better management of the transportation infrastructure.

Table 5: Daily traffic volume results compared to base case at the corridor level

Bridge	% Diff		
	Shipper	Planner	PolicyMaker
Gov. Harry Nice Memorial Bridge (North Bound)	16%	-2%	10%
Gov. Harry Nice Memorial Bridge (South Bound)	15%	-1%	14%
Woodrow Wilson Memorial Bridge (North Bound)	11%	0%	12%
Woodrow Wilson Memorial Bridge (South Bound)	75%	-1%	10%
American Legion Memorial Bridge (North Bound)	18%	-4%	10%
American Legion Memorial Bridge (South Bound)	22%	-1%	12%
Conovingo Road Hwy (North Bound)	44%	-3%	11%
Conovingo Road Hwy (South Bound)	52%	0%	10%
John F Kennedy Memorial Bridge (North Bound)	8%	-4%	12%
John F Kennedy Memorial Bridge (South Bound)	22%	-2%	10%

Figure 4: Major Bridge Locations

6. CONCLUSION

This study envisioned the design and application of freight transportation modeling techniques to quantitatively assess the impacts on highway traffic of three distinct scenarios based on perspectives that could significantly influence decisions in freight transportation planning and policy. Stakeholders of these three perspectives were shippers, planners, and policy makers whose primary objectives are different from each other. The shippers' objective is to transport various commodities from origins to destinations with minimal cost, which includes travel distance, time, toll, reliability, convenience, and other factors. The planners' objective is to design and manage the transportation system by the modal shift from trucks to rail to address environmental problems. The policy makers' objective is to bring an economic growth to the region. The analysis results were presented at three geographic/physical levels (1) statewide level, (2) facility type level, and (3) link level to gain a broader picture of the transportation system. Performance measures—VMT, CLM, and VHD were used to numerically show how the transportation system is affected by each of these three objectives.

In summary, the relative comparison of performance measures under different policy scenarios is important in assisting policy decision making. This paper has three main contributions to research. First, we developed a methodology to clearly incorporate freight trips in a travel demand model that takes into account state, regional, and local levels (with an emphasis on the state level). Second, the objectives of key players are identified and incorporated in the scenario analysis in freight planning to demonstrate the capability of the developed statewide travel demand model. Third, the use of FAF data in truck travel behavior is another substantial improvement in this study, as FAF allows the model to preserve commodity flows in international, national and regional levels and also at the local TAZ level with finer disaggregation of trips. The proposed three layer methodology allows capturing these different scales of freight flows in one model.

The paper has two main contributions to research. First, the proposed methodology and statewide freight model addressed a significant shortcoming in conventional MPO and statewide travel demand models that do not incorporate freight trip generation and distribution in detail, but consider only external centroid connectors to represent long distance freight trips. Second, the proposed methodology simultaneously takes into account passenger cars and trucks in the model, and thereby, estimates the effects of both categories of vehicles on congestion in the traffic assignment stage. In addition, this proposed model provides more realistic estimates of traffic volume and congestion at the link level for different policy scenarios, and allows policy makers and planners to identify congested roadway segments for future improvements.

The research presented in this paper can be extended in future in many ways. It seems that the most important improvements for freight modeling are in the realm of freight mode choice. First, the model could be improved by properly examining policies that induce changes in freight mode choice, which are not adequately represented by a fixed demand in the FAF data.

Second, with data on entities' preferences of freight mode choice, the proposed methodology could be further improved. Modeling freight mode choice has been a challenging task as a choice by shipping entities depends on a variety of factors, including type, weight, and value of commodity, costs for storage, and urgency of shipment.

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