A Framework for Megaregion Analysis: Development and Proof of Concept

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EXECUTIVE SUMMARY

In many parts of the world megaregions, large agglomerations of metropolitan areas and their supporting hinterlands, represent an emerging development pattern. Examples in North America include the Northeast corridor in the United States covering Boston, MA to Richmond, VA and the industrial areas of the United States and Canada surrounding the Great Lakes. One challenge is to determine how to foster greater efficiencies in these megaregions by creating a stronger infrastructure and technology backbone in the Nation's surface transportation system. To function effectively, and to allocate scarce resources to infrastructure investment, megaregions must not only understand their relationships with other megaregions, but must also understand their own region's internal economic flows and the interactions between these flows and the transportation system.

Analytic methods are needed to address these issues at the megaregion level. This report first proposes an analytic framework for analyzing megaregion issues, then develops a proof of concept application of the framework to the Chesapeake megaregion (CM).

FRAMEWORK

Typically, a megaregion analysis framework should include two parts: market analysis and tool development. The market analysis reveals significant economic and transportation characteristics in the megaregion. Based on the market analysis, the tool development process then tailors the analytic tools to the megaregion issues and conditions.

Market Analysis

The market analysis consists of three components: identifying the core issues, identifying the megaregion boundary, and characterizing the megaregion. These steps are interrelated. Depending on the circumstances, the market analysis may start with any of the three steps.

Identify Issues. Each megaregion is unique in terms of core issues that tie the megaregion together. Different issue focuses may result in different geographic boundaries and analysis themes. Issues could be environmental, political, economic and etc.

Identify Boundary. The geographic boundary provides the basis for most data collection and analysis of the megaregion. The boundary may vary, depending on the issue to be addressed.

Characterize Megaregion. A two-tiered analysis is appropriate for megaregion characterization: first understanding the megaregion as an entity, identifying the relationship to other megaregions and the national/global economy, and then analyzing intramegaregion flows and relationships.

After completing the market analysis, three questions should be clear: what are the critical issues that the megaregion needs to address, what the megaregion boundary is, and how the elements within the megaregion have been tied together, in economic structure and in infrastructure-based geography.

Figure 1 Framework for A Megaregion Analysis Tool
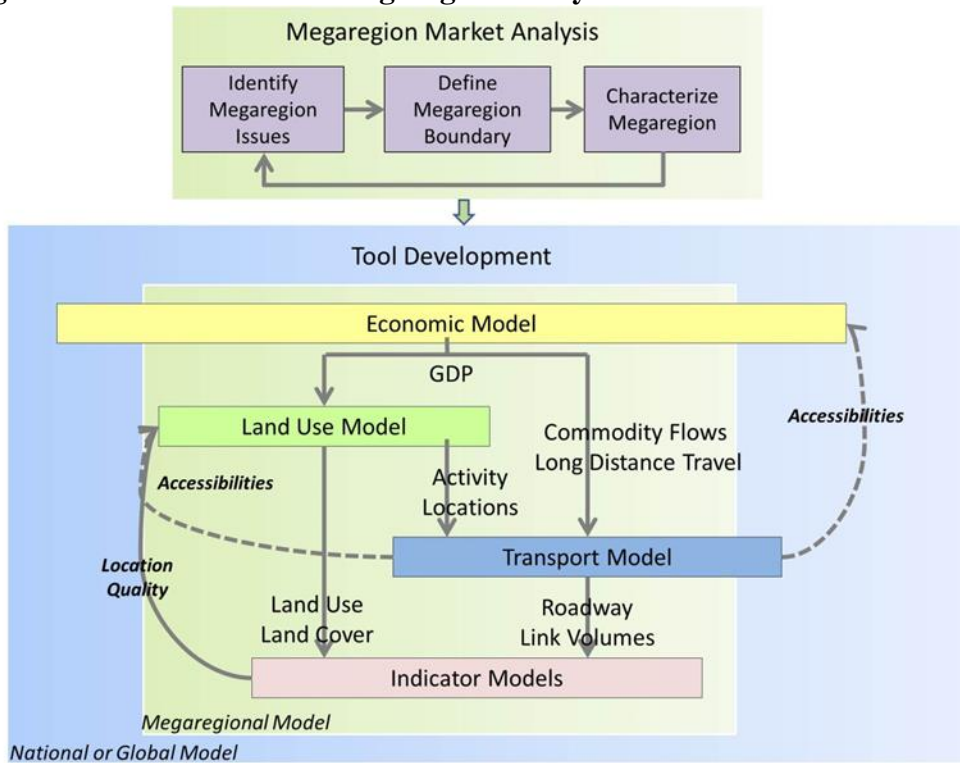
Tool Development

The market analysis reveals the economic organization and structure within a megaregion, and a tool development process can help to build up a focus model and conduct further analysis, such as the future year prediction and policy scenario testing.

A multi-tiered approach with three layers – Global, megaregion, and MPO/DOT layers - represents the context for travel decisions by the market segments important to megaregions. This approach enables tailoring the spatial scale to various data and decision-makers represented in the model components. It also facilitates the integration with existing local MPO/DOT models. Probably most important is to tailor this framework to the policy questions of the particular megaregion.

The megaregion analysis tool should include short and long distance freight flows as well as passenger movements. As such, it is more appropriate to employ integrated models where travel is driven by economic and land use decisions, and employ a multi-level model where activities are assessed at an appropriate national, megaregional, or local context reflecting the scale at which the phenomenon occurs. Such a suite of models would aspire to address:

- Economic, Transportation, Land Use and Environmental Impacts.
- Multi-Modal Transportation Systems.
- Short and Long Distance Travel.
- Multi-Scale Projects.

- Unique issues and technical requirements associated with modeling at the megaregion level.

The level of detail, at which each element of the framework operates, very much depends on the policy questions that are likely to be asked. The following describes each of the framework components:

Economic model (yellow in Figure 1).Changes in the national economy will have effects on the megaregion, both with respect to growth in population and employment and trade with other megaregions. Important economic interactions occur at geographies that are larger or smaller than political units, or at a scale comprising many smaller units. Larger and/or more complex geographies may better represent the spatial dimension of the most successful integrated economies. In addition, the economic model should interact with other megaregions and the national economy.

Land-use model (green in Figure 1).The land use model forecasts the likely location of future population and employment subject to economic growth and changes in the transportation system.

Transport models (blue in Figure 1). Transport models forecast the number of trips made, their origins and destinations and the mode chosen. They do this for short and long distance passenger trips, short, and long distance freight trips. The assignment provides revised travel times that may be used to calculate accessibilities, an important driver for economic and land-use changes.

Indicator models (pink in Figure 1).Indicator models are post-processor models, which are used to analyze specific issues of a megaregion. Examples are air quality, water quality and local economic impacts.

CHESAPEAKE MEGAREGION

The Chesapeake Megaregion around Washington D.C. is a case study to this megaregion framework. With a population of 15 million contributing 6% of the national GDP, the Chesapeake Megaregion is a typical and important coastal megaregion in the country.

Market Analysis

The Chesapeake Megaregion faces multiple issues, including the environment, the health of the Chesapeake Bay, continuing urban sprawl, the economy and growing traffic congestion. While all of these issues are critical, this report focuses on the economy of the megaregion. The economy is a major issue in most parts of the U.S. and designing efficient infrastructure systems supports economic development.

Defining the boundary of a megaregion must be done on a case-by-case basis and depends on existing political boundaries, the infrastructure of the megaregion and the issues to be addresses. Unlike states and MPOs, megaregions do not follow strict boundary definitions. In the case of the Chesapeake megaregion, the initial boundaries were based on a report by Dr. Catherine Ross

from Georgia Tech, covering most of Maryland and Delaware and portions of eastern Virginia. In order to understand the economic interactions, the boundaries defined by Ross were expanded to cover all of Maryland, southern Pennsylvania and all of eastern Virginia. To capture freight movements, New Castle County, Delaware, and the Port of Wilmington are also included.

An extensive characterization of the Chesapeake Megaregion was conducted. The characterization began with commuter flows, showing that there are three main commuter sheds in the megaregions: Baltimore-Washington, Richmond and Norfolk-Virginia Beach. The ports complement each other with Wilmington providing primarily for oil imports, Baltimore serving shorter distance freight travel, usually truck trips less than 400 miles, and Norfolk serving a larger community with nearly 50% of traffic to and from the port moving by rail. The megaregion is tied together by major Interstate links, in particular I-95 and I-64. These links form the backbone of the megaregion. It contains three major ports, Wilmington, Baltimore and Norfolk and three major airports, Baltimore Washington International, Washington Reagan and Washington Dulles. In addition, AMTRAK, the Chessie System and Norfolk Southern provide major rail service for passengers and freight. A review of FAF data showed that most goods entering or leaving the megaregion traveled by truck.

An analysis of county-to-county freight flows showed that freight movements within the Chesapeake Megaregion tie the megaregion together. This is exemplified by both the dollar value of freight flows as well as the tonnage. A large portion of this freight movement is in the north south direction along the I-95 corridor. The characterization also looked at freight flows in and out of Baltimore, Washington and Richmond to the rest of the megaregion. The analysis showed that these cities are interconnected by both import and export freight flows. The location of the origin and destination of these flows showed that the majority of these movements occur along the I-95/I-64 corridors.

A supply chain analysis was also conducted, looking at key shipments into and out of Richmond and Baltimore. This analysis showed that each of these cities imported goods from other areas, processed them, and then sent them on to other locations. Richmond processed a large share of paper products and Baltimore materials for soft drinks and ice manufacturing. These shipments, particularly shipments from Richmond to Baltimore, demonstrated how closely freight movements tie the megaregion together and that north-south movements dominate freight flows. An additional analysis was conducted on the effects of a 1% increase in the Baltimore and Richmond economies. This analysis showed that an increase of this type would affect surrounding counties and provide ripple effects throughout the entire megaregion.

The transportation model, which included internal and external passenger and freight flows, estimated future passenger and truck travel and the effects of changes in travel patterns on the highway network. Truck trips greater than 50 miles were shown to have a major impact on VMT but accounted for a small number of total truck trips. Using the transportation model to look ahead to 2030, large increases in congestion were observed along the I-95 corridor, particularly in the Washington DC area. An analysis of future freight flows showed that this congestion, combined with the growth in freight traffic, would increase the cost of freight travel, particularly in the North-South direction.

The market characterization leads to conclusions about the Chesapeake megaregion and megaregions in general.

Tool Development

A comprehensive model has been established for further analysis. The implemented components can be summarized as follows:

National Economic Model. Forecasts marginal consumption and production in 65 economic sectors and allocates these forecasts to states.

Land Use Model: Zonal Level Allocation. State-level forecasts of basic employment are allocated to counties, then retail and service employment, along with population, is located.

Transport Model
- Long Distance Freight. The truck portion of the economic model's commodity flow output is disaggregated from FHWA FAF zones to model zones using employment data and inter-industry input-output relationships.
- Long Distance Person. The Nationwide Estimate of Long Distance Travel (NELDT) model using NHTS long distance travel data and traveler attributes forms a national model of long distance travel.
- Short Distance Person. A 4-step travel model from one of the local MPOs was transferred and applied region-wide.
- Commercial Vehicles. A commercial vehicle model from one of the local MPOs was applied megaregion-wide.
- Assignment and Time of Day. Transit networks within the megaregion are represented along with volume delay functions and time of day factors.

Indicator Model
- Greenhouse Gas Emissions. The EPA MOVES model is used.
- Water Quality. A nutrient loading model uses detailed land cover changes from the parcel-based land use model to identify changes in nutrient runoff experienced in each watershed. The water quality model requires parcel level land coverage data. (Note: The current model estimates impacts only from Montgomery County and not from the entire Chesapeake Bay watershed.)
- Infrastructure Costs. An infrastructure cost model forecasts needs based on relationships between urban/rural development and the provision of infrastructure required for the forecast development pattern. The fiscal indicator model has been developed to reflect conditions and costs in Maryland.
- Parcel Level Detail. A Cellular Automata model (LEAM model) calculates probabilities of the potential for each cell to change from one land-use category to another, influenced by adjacent cells. This model was used only for water quality estimates and is described further in Appendix D, indicator models

Using the model, two fuel price scenarios have been tested to measure traffic and environment effects.

High Energy Price Scenario

To exercise the analysis framework on CM issues, two possible future energy price scenarios were identified spanning the possible effects: Reference, in which the price of petroleum rises slightly and MPG remains the same; and a Price Spike in which the price of energy remains relatively constant through 2029, then jumps to a very high level in a very short period of time.

Components of the basic Chesapeake Megaregion Model related to auto-operating cost (AOC) were adjusted to reflect the scenario of an energy price surge.

In the short distance person travel model changes included: (1) trip generation rates varying with AOC, using elasticity's assessed by a Delphi panel of experts in travel demand modeling; indicating higher impact to discretionary travel and increases in trip chaining with more sensitivity found in lower incomes; (2) asserted Mode Choice model coefficients, incorporating a value of time variable in the utility function, enabling appropriate price response by income group; (3) re-specification of the accessibility measure used in the mode choice and destination choice model to include auto operating cost in addition to traditional time and cost metrics. The accessibilities were also used in the megaregional economic post-processor; (4) long distance person travel was assumed to be limited to a constant travel budget with increased AOC leading to reduced number of trips and shorter travel distances.

Scenario Results

A sudden energy price spike would likely have an immediate impact, primarily on travel but also on the economy.

Residents can be expected to reduce the number of trips, change trip destinations to allow for shorter trips, using more direct routes, chaining of multiple trips, as well as increase the use of any alternative transportation options available to them, such as carpooling and transit services.

In the Baltimore-Washington area, where a wide range of transit options are available, the analysis showed a significant increase in transit ridership. In contrast, outside the Washington D.C. suburbs, urban areas in Virginia do not have a high level of transit service and instead shifted to carpools and shorter trips. The analysis highlights the non-urban and low-income communities are more vulnerable to rising energy prices. The resulting drop in personal auto vehicle miles traveled lead to congestion relief, with congested speeds an improvement relative to 2007 levels.

For freight movements, the economic impact of a price spike would be mixed. The case study makes two assumptions with respect to freight. First, the cost of shipping is borne primarily by the shippers, not the freight carriers, reflecting long term contracts. Second, in industry processes, particularly those requiring assembly of intermediate goods and shipment for final assembly, destinations cannot be easily changed. Thus, by lowering congestion the decrease in traffic can actually have a net benefit to freight and the economy. This benefit can be particularly important for shipments, which are high value and /or time sensitive. Particularly in

urban areas, they were able to move more quickly due to the reduction in person travel, and associated congestion relief.

Combined Policy Impacts

A Megaregion Board (MRB), a hypothetical body charged with planning for a megaregion, could use tools similar to those in the case study to analyze policies in isolation or combination, to determine their collective effect on the megaregion and on local jurisdictions. In the megaregion view, policies in one jurisdiction can have spillover effects on the rest of the megaregion. Individual areas can develop policies, which are optimal for one area, but have negative effects on adjacent areas. Within the megaregion, with the linkages spanning many jurisdictions, the spillover effects can be wide ranging. For example, policies that attempt to foster economic development in one area may have the effect of removing development from another area.

While this study did not address security issues directly, the threat is particularly severe in the Chesapeake Megaregion, home to the nation's capital and numerous military bases. For example, an evacuation from Washington, DC would likely tie up the entire I-95 corridor, affecting traffic flows from Philadelphia to Richmond and beyond. In the event of a natural disaster such as a severe hurricane, travel through the CM could be disrupted and it would be critical to move relief supplies in and people out. This type of planning can only be accomplished at the megaregion level, and the CM analysis tool would provide a useful framework for such a study.

CONCLUSION

This case study identified factors significant to a megaregion body, including that the CM is tied together economically and that in addition to land use, transportation and the economy, the CM should address specific policies at the megaregion level, such as emergency preparedness and the collective impact of individual local policies. The analysis framework has helped to identify these policies. The framework could also serve to test the impact of implementing such policies in a coordinated or uncoordinated way across the jurisdictions within the megaregion.

On a technical level, the project demonstrated that data from multiple sources can be combined to develop a multi-discipline, multi-level model and that the model can be applied on a large geographic scale encompassing a key US megaregion. On a policy level, the project demonstrated the impacts of high-energy prices on the economy, land use, transport, and environment of the megaregion as a whole as well as highlighting vulnerable communities and industries. The case study characterization and scenario analysis highlighted how the CM is linked together economically and the value of analyzing a wide range of issues with a broad megaregion perspective.

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1. INTRODUCTION

1.1. BACKGROUND

The Federal Highway Administration (FHWA) contracted with the National Center for Smart Growth (NCSG) at the University of Maryland to conduct research on "megaregions."[1] A typical megaregion is defined as a set of interconnected central cities and their economically linked hinterland. The concept of megaregions derives from the observation that as urban regions growth, transportation, and communication links improve, it is in their best interest for multiple urban areas to act together as an economic unit.

The specific objective of this research project is to (1) recommend a framework for megaregions to use in analyzing issues and (2) test the ability of the framework to provide a suite of forecasting and evaluation models using the Baltimore / Washington D.C. / Richmond / Norfolk megaregion (referred to here as a the Chesapeake megaregion, CM) as a case study. This report covers the results of this project. The report includes:

Megaregion Concepts and Framework

- What is the need for megaregions? What issues do they face and what is important about viewing issues from the megaregion perspective?
- How should an analysis framework for modeling of a megaregion be structured? What components should it contain and how should those components be designed and interact?

Megaregion Case-Study/ Scenario Development

- How is the Chesapeake Megaregion characterized? What are the boundaries of the megaregion, what are the economic land use, and transportation linkages? What other issues are of concern (e.g. greenhouse gases, health of the Chesapeake and the local fiscal impact of growth)?
- What are the key issues for this Megaregion? How was the High-Energy Price scenario selected, and what are the assumptions behind it?
- What is the analysis framework used for this case study? What modifications or adjustments are made to the recommended framework previously presented? How did the framework evolve for this megaregion and to address the chosen scenario?
- What are the results of the scenario? What can be said about the current and future economic, transportation and land use results? What can be said concerning environmental impacts and impacts on the megaregional economy?

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[1] The full research team includes NCSG, ECONorthwest, Parsons Brinkerhoff, the LEAM Group of the University of Illinois at Urbana/Champaign, and David Simmonds Consultancy.

Megaregion Board

The case study assumes that there is a megaregion board with concern about policies and developments within the megaregion.

- What would the case study tell the board about economic, land use and transportation policies and investments under a high-energy price scenario?
- What is the value and importance of the megaregion view of these issues?

Appendices

The appendices contain important supplemental information about megaregions in general and the technical details the technical aspects of the case study. Appendices include:

- Literature Review
  - Megaregion Examples
  - Megaregion issues and value
- Case Study input data
  - Zone system and networks
  - Socio demographic data – economic and land use models
- Case Study Framework
  - Megaregion economic, land use, transport model methods
  - Model adjustments and assumptions for the High Energy Price Scenario
- Case Study Indicator Models
  - Megaregion indicator model methods (Greenhouse Gas emissions, nutrient loading, public infrastructure fiscal costs, economic post-processor)

2. MEGAREGION CONCEPT
2.1. THE NEED FOR A MEGAREGION VIEW

The expansion of major metropolitan areas over the last several decades, facilitated in part by investments in auto-oriented transportation infrastructure, has resulted in the integration of large polycentric urban agglomerations, or "megaregions." With the baby boom generation entering retirement at a time when this cohort has amassed considerable housing wealth and with the increased mobility of highly educated workers, megaregions are becoming the typical urbanization pattern. By as early as 2050, they will contain two-thirds of the nation's projected 430 million residents (Amekudzi, Thomas-Mobley, Ross 2008; Carbonell and Yaro 2005).[2]

These new urban patterns create new opportunities and challenges for planners and policy makers. On the one hand, megaregions offer distinct agglomerative benefits that make such areas more competitive in the global marketplace. Megaregions have a sufficiently diverse economic and land supply base that the entire value chain of a given multi-national firm would be able to locate its different functions within the megaregion rather than off-shoring activities for different functions (Sassen 2007). On the other hand, megaregions extend beyond traditional political boundaries, making policy implementation and coordination much more difficult, particularly given the dearth of megaregional institutions.

2.2. MEGAREGIONAL ISSUES[3]

Megaregions comprise the economic engine of the US, forecasted to contain half the nation's population growth and perhaps up to two-thirds of its economic growth by 2050 (Amekudzi, et al. 2007). Supporting the economic competiveness of these megaregions domestically and abroad is a key concern given increasing global competition and international trade. A primary justification for addressing policy issues at a megaregional scale as opposed to the metropolitan scale is that megaregional economic activities are increasingly linked in such a way that economic shocks to a given metropolitan area result in spillovers, both positive and negative, to adjacent metropolitan areas. Consequently, the resultant environmental and social impacts associated with such activities likewise spill across metropolitan areas. Furthermore, as pointed out by Christaller (1933), Lösch (1954), and Ross and Woo (2009), individual cities are part of larger systems that are linked by inter-city trade hierarchies.

Megaregions are a development pattern evident throughout the world. Examples in North America include the Northeast corridor in the United States covering Boston to Richmond and the industrial areas of the United States and Canada surrounding the Great Lakes. The Federal Highway Administration's Strategic Plan states that megaregions are likely to be the "nation's operative regions when competing in the future global economy. A challenge is to determine how to foster greater efficiencies in these megaregions by creating a stronger infrastructure and

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[2] This paragraph is taken from the Literature Review, Appendix A

[3] Section 2.1.1 is based on the paper Megaregions develop as complex systems: Horizontal and vertical integration for a Megaregion Simulation Model submitted to ASCE by Moeckel, Rolf; Mishra, Sabyasachee, Ducca, F and Weidner Submitted to ASCE November, 2011 and the Literature Review

technology backbone in the Nation's surface transportation system."[4] Indeed, the economic engines of European and emerging countries also reside in megaregions often bound by high-speed rail.

Megaregions now compete with each other for economic development as well as complement and connect each other. They also face internal economic issues and demands for infrastructure investment. Unlike states and MPOs, which are defined by political boundaries, megaregions are defined by unifying economic, demographic or environmental factors. Megaregions may have significant effects on the national economy and connectivity within and between megaregions; this will be a critical issue. Indeed, megaregions dominate the coveted knowledge workers of the 'creative class', encompassing over 60% of U.S. counties with higher than average share of such populations.[5]

Many planning decisions are more appropriately made at the megaregional level than at the traditional MPO or state level. The larger scale is relevant in cases of spillovers, economies of scale, demand heterogeneity, and administrative cost efficiencies. Through a comprehensive literature review as well as experience working on specific projects, issues and models, the team has identified issues that ought to be addressed at the megaregional level.
 Policy issues exhibiting the following characteristics are most appropriate for a megaregional level of analysis:

- Issues involving large spillovers, which extend beyond existing local, regional, and possibly state governance arrangements but not to the scale of the entire nation. Investments involving large-scale economies, which are exhausted at the megaregional scale.
- Issues for which, public sector demand is relatively homogeneous at the scale of the megaregion.
- Issues which involve a redistribution of resources across metropolitan areas or states but which benefit from local (megaregional) knowledge regarding the nature of the redistribution.
- Issues that can be addressed with low administrative costs at the megaregional scale. If there were economies of scale in administration, then megaregional governance would be preferred to local governance arrangements.

Specific examples of issues that are more appropriately addressed at the megaregion level are described below.

Environmental

The following environmental issues are best suited for a megaregional policy framework:

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[4] Appendix A, the literature review, contains a detailed discussion of the evolution toward megaregions and issues which Megaregions face.
[5] From Lang, Nelson, Megapolitan America, (2011). It uses the USDA's Economic Research Service classification and datawhich expands on Richard Florida's 2002 book, The Rise of the Creative Class.

Climate change. Air quality issues can go well beyond metropolitan borders. Greenhouse gases are a worldwide issue and larger units of analysis are critical to addressing the problem. The Regional Greenhouse Gas Initiative (RGGI) is an agreement among ten Northeastern states to regulate emissions from power plants through a "cap-and-trade" system, where limits are placed on the total pollution emitted from power plants, and emissions permits can be bought and sold to meet carbon emissions standards (Todorovich 2009). This issue is best addressed at the megaregion scale when heavy polluters cannot easily avoid cap-and-trade regulations by relocating to other megaregions. Larger-scale climate changes produced by non-point source pollution, and the resultant impacts including sea-level rises and destruction of property and infrastructure along the coast, are also appropriate for megaregional policy intervention.

Megaregion water resource management. Like air quality, the region affecting water quality issues can be larger than a metropolitan area. If water quality is to be analyzed effectively, the entire watershed of the body of water in questions must be included in the analysis. The Great Lakes Commission was established in 1955 to govern water resource management through a compact agreed upon by the eight states surrounding the Great Lakes. The Commission provides recommendations for the use and conservation of water, public works and improvements, improvements to navigation and ports facilities, and other strategies, which serve to protect water quality within the Great Lakes Basin (Great Lakes Commission n.d.).

Transportation

Transportation is key to economic linkages within the megaregion:

High-speed rail. High-speed rail systems connecting metropolitan areas within a megaregion are frequently cited as a megaregional issue. High-speed rail provides an intermediate form of transportation, faster than an automobile but slower than air travel. However, for intermediate distance trips, those, which require faster travel time than the auto but are not necessarily long enough, require the boarding delays and access times associated with air travel, high-speed rail can be competitive. In Europe, high-speed rail unites megaregions increasing their reach for labor expertise and agglomeration, thereby incurring competitive advantage for the megaregion. The Southern California Megaregion is currently developing plans for a high-speed rail system that relies on magnetic levitation (Maglev) technology to connect regional airports to urban centers such as Los Angeles, Riverside, San Bernardino, and Orange County. When finished, the system will cover 275 miles and move up to 500,000 riders per day (Kern County Council of Governments, et al. 2005). The introduction of new high-speed rail systems might also result in significant changes to other travel modes, such as regional air travel, suggesting a need for megaregional coordination of multi-modal facilities.

Management of congestion on interstate highways through coordinated tolls and congestion pricing. Improvements in transponder technology now make congestion pricing important at a megaregion scale. If technologies differ between metropolitan areas, such pricing strategies will be more costly to implement and cumbersome for users (Glaeser 2007). For example, the E-Z pass-toll collection system provides a uniform pricing technology for those traveling along I-95 in the Northeast. This technology was made possible through the I-95 Corridor Coalition, an alliance of state departments of transportation, metropolitan planning

organizations, law enforcement agencies, and transportation industry associations that span the length of I-95 from Maine to Florida (Todorovich 2009).

Freight movements. Much of freight involves long distance movement represented at the megaregion level, requiring a larger analysis area than a state or MPO model; particularly when analyzing tradeoffs between highway and rail.

Multi-urban area policies/investments. Cumulative effects of policies implemented across multiple urban areas, such as growth management or freight infrastructure investment. The planning efforts for the I-95 corridor on the east coast are a prime example. Disaster Response/emergency Preparedness planning involves multiple jurisdictions. Short term disaster responses (e.g., Hurricane Katrina in New Orleans and 9/11 in New York and Washington) influence the megaregional transportation network. Long term disaster responses (e.g., Hurricane Katrina and 2010 Gulf of Mexico oil spill) may have long term effects on the economy, land use and the transportation system.

Port expansion. The volume of international trade occurring through major U.S. ports is projected to be much higher in the future. Since most major ports are located in megaregions, estimated trade volumes over the next 25 years are projected to be concentrated within megaregions (Ross and Woo 2009). This is an issue of importance to megaregions, because the increased volume of goods flowing into major ports will require significant upgrades to port facilities and freight distribution networks connecting ports to domestic markets.

Economic Development

Economic development often occurs at the megaregion level. Some examples follow:

Competition among megaregion industry locations. In complex manufacturing processes such as the automobile, multiple firms may make parts of the final product, and then ship them to the manufacturer for final assembly. At the same time, local governments often engage in "smoke-stack chasing," offering tax breaks and other incentives to lure firms from adjacent jurisdictions within the same megaregion. This form of local government competition wastes scarce tax base resources and often incentivizes inefficient firm location decisions. Megaregional coordination of economic development incentives can help to minimize the incentives to engage in such inefficient local government competition.

Full supply - chain job opportunities. Megaregional coordination of economic development incentives can also help to diversify the megaregion's economic base. Most economic development incentive programs focus on top-tier "knowledge economy" industries and ignore low-wage sectors, many of which have moved offshore. By focusing on the entire value chain within a megaregion, Sassen (2007) makes a case for diversifying the package of incentives offered to firms and attracting low wage industries that may have linkages to firms higher up the value chain. Activities such as low-cost manufacturing and back-office functions that are currently outsourced to other countries could be accommodated within a megaregions' rural areas, because the urban cores of megaregions are not competing with such functions due to their higher land values and labor costs (Ross 2008).

Cross-Cutting Issues

Several issues appropriate for megaregional policy intervention span each of the substantive policy domains mentioned above. These include:

Megaregional natural disaster response. Hurricane Katrina, which struck the Gulf Coast megaregion in 2005, caused massive property damage and widespread displacement in an area that stretches from Pensacola to greater Houston. The decline in population within the area affected by the hurricane and the influx of new residents into cities such as Houston placed heavy demands on public services. It is now widely acknowledged that pre-existing local, state, and federal disaster response systems were inadequate to address the full range of issues posed by the storm. Since the entire Gulf Coast megaregion lay in the path of Katrina's destruction, coordinating disaster prevention and response efforts at the scale of the entire megaregion would have allowed for an assessment of the extent to which assets and population were displaced from affected regions to neighboring regions (Lang 2006). Megaregional coordination of disaster response networks would have facilitated both a more expansive short term emergency response in addition to facilitating a more comprehensive long term rebuilding effort.

Other man-made disasters such as blackouts affecting large power grids and rises in sea levels induced by global climate change point to a role for megaregional policy intervention.

2.3. MEGAREGION BOARD

With the grow of megaregions and the clear identification of issues which are appropriately addressed at the megaregion level, an oversight body or board with the ability to address megaregion issues would be of great benefit to many areas. This body would provide input to decisions, which affect the entire megaregion and might have functions similar to those of an MPO, but with a wider coverage area. Depending on how it was, set up the board could also have the ability to advise various levels of government on issues related to the megaregion. In particular, the board would inform on policies or actions, which would impact the entire megaregion. A megaregion board, empowered to address megaregion policy, would address issues which go beyond individual urban areas and which, if not properly addressed, would negatively influence the entire megaregion and the areas within the megaregion.

Such a board would need analytic tools to support their policy analysis. The analytic tools should be able to address issues, which the megaregion board would face and be able to be modified to address new and emerging issues. The remainder of this report discusses a framework, which can serve as a blueprint for megaregional analysis.

Ideally, analytical tools (models) should be developed that respond to any of these megaregional issues. Such a suite of models would aspire to address the following:

Economic, Transportation, Land Use and Environmental Impacts. Megaregion models must support decisions related to the interactions of transportation, economic, land use, and the environment. Such models will quantify interactions between cities and counties, guide economic investment, the provision of new transportation infrastructure, the location or

relocation of a large numbers of workers, and shape policies for megaregion environmental issues. Modeling at the megaregional level quantifies connections to the economy and captures opportunities for megaregional shifts in land use. Additionally, environmental impacts and emission are important criteria to evaluate policies.

Multi-Modal Transportation Systems. The modeling framework must be able to evaluate both freight and passenger travel in a multi-modal transportation system. This includes freight modes and capacities (e.g., truck, rail, marine), as well as the various local transport modes (e.g., auto, commuter rail, high-speed rail, air travel).

Short and Long Distance Travel. The modeling framework should encompass all trip purposes and trip lengths. Besides the common purposes in short distance travel, the framework needs to address long distance business, personal, and commuting travel, both within and between megaregions. Likewise, freight travel can be distinguished between long haul commodity flow movements and short distance distribution and service trips, typically by truck. Both short and long distance travel needs to be represented in a megaregion model for understanding actions under changing conditions and reflecting network demands and congestion. There are several differences between short and long distance travel requiring that separate analyses for each:

- **Timing.** Long distance travel may be made over a period of several days while short distance travel usually returns to a starting point at the end of the day. Long distance trips do not follow the typical AM/PM peaks of short distance trips.
- **Origin/Destination.** The frequency and endpoints for travel differ between long and short distance travel. Person long distance travel is more frequently done by high-income households, with destinations ranging from business districts to recreation facilities and parks. Long distance freight is typically business-to-business commodity-flow based, with some warehousing and wholesaling, while short distance freight is more retail focused, with home deliveries and services, more amenable to a tour-based approach.
- **Modes.** Long distance trips have different rules for mode choice than short distance trips. Long distance person trips may go by air and may not have public transit as an available mode. Long distance freight is more likely to have modal options.
- **Routes.** In selecting routes, short distance travelers typically have better access to local information about routes and congestion.

These different attributes make it technically challenging to model both short and long distance travel together, warranting separate models within the framework. Given the large number of long distance trips in a megaregion, the separation of short and long distance trip distribution modules improve the overall model performance noteworthy.

Multi-level Projects. The modeling framework should permit evaluations of projects at the megaregional scale. Examples of projects include high-speed rail, freight corridors, warehouse distribution centers, and port facilities, as well as the cumulative impacts of a broad implementation of smaller scale policy actions. Although the latter is a challenge at the megaregional scale, the megaregion model should be sensitive to local projects, possibly done in collaboration with more detailed MPO models.

Diversified Megaregion Context. According to Dr. Ross[6] and America 2050[7], about ten twelve emerging megaregions in the United States have been identified. These megaregions vary significantly in terms of size, economy, domestic and international trade partners, existing transportation infrastructure characteristics, available data sources, and policies of interest. The recommended analytical framework needs to be flexible enough to be transferable to any of these emerging megaregions.

2.4.   FRAMEWORK FOR MEGAREGIONAL ANALYSIS: OVERVIEW

The framework must be able to respond to the requirements identified above. The megaregion analysis framework should consist of two parts, the market analysis which identifies megaregion issues, boundaries and characteristics; and tool development, which develops a model or set of models to address the megaregion issues.

Since megaregions encompass a larger area than typically covered by MPOs or state DOTs, a larger analytic view is required. This requires the inclusion of economic motivations for travel and a focus on longer distance inter-city travel by freight and persons. However, some of this local detail must remain to enable sensitivity to policies where changes in local conditions may affect the megaregion and where evaluation of performance measures requires such detail.

Modeling for megaregions is similar in many ways to the traditional travel models developed by MPOs and State DOTs; trip generation, distribution, mode choice and assignment procedures. However, due to the scope of megaregions and the nature of issues to be analyzed, megaregion models can also have significant differences from traditional travel models. These differences may include:

Interaction with other megaregions and the nation – Due to the size of the megaregion, at a low level of detail a megaregion model should capture the economic and long distance transportation interactions with the national economy and with other megaregions and the rest of the country.

Distinction between short and long distance travel - A megaregion analysis framework must include short and long distance travel for both freight and passenger movements. As such, it is more appropriate to employ integrated models where travel is driven by economic and land use decisions, and employ a multi-level model where activities are assessed at an appropriate national, megaregional, or local context.

Multi-tiered approach - A multi-tiered approach with three layers is recommended to best represent the context for travel decisions by the market segments important to megaregions (Figure 2). The top layer represents modeling and activity at the national and international level, the middle layer at the Megaregion level and MPO/DOT layer represents the state and MPO

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[6] Delineating Existing and Emerging Megaregions; Report to the FHWA; Georgia Tech Research Corporation. PI: Dr. Catherine L. Ross, Co-PIs: Jason Barringer, Jiawen Yang (2009).
[7] America 2050 Initiative. (http://www.america2050.org/publications.html).

activity along with all other modeling and data sources. The arrows indicate that information flows up and down between each layer.

Figure 2 Multi-Tiered Approach
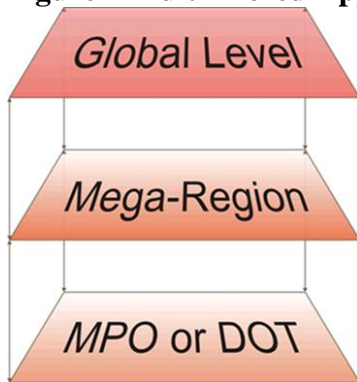
A framework example is shown in Figure 3. Typically, a megaregion analysis framework should include two parts: market analysis and tool development. The market analysis defines issues and boundaries, and characterizes the economy and transportation flow within the megaregion. Based on the market analysis, the tool development process then tailors the analytic tools to the megaregion issues and conditions.

Figure 3 Megaregion Analysis Framework
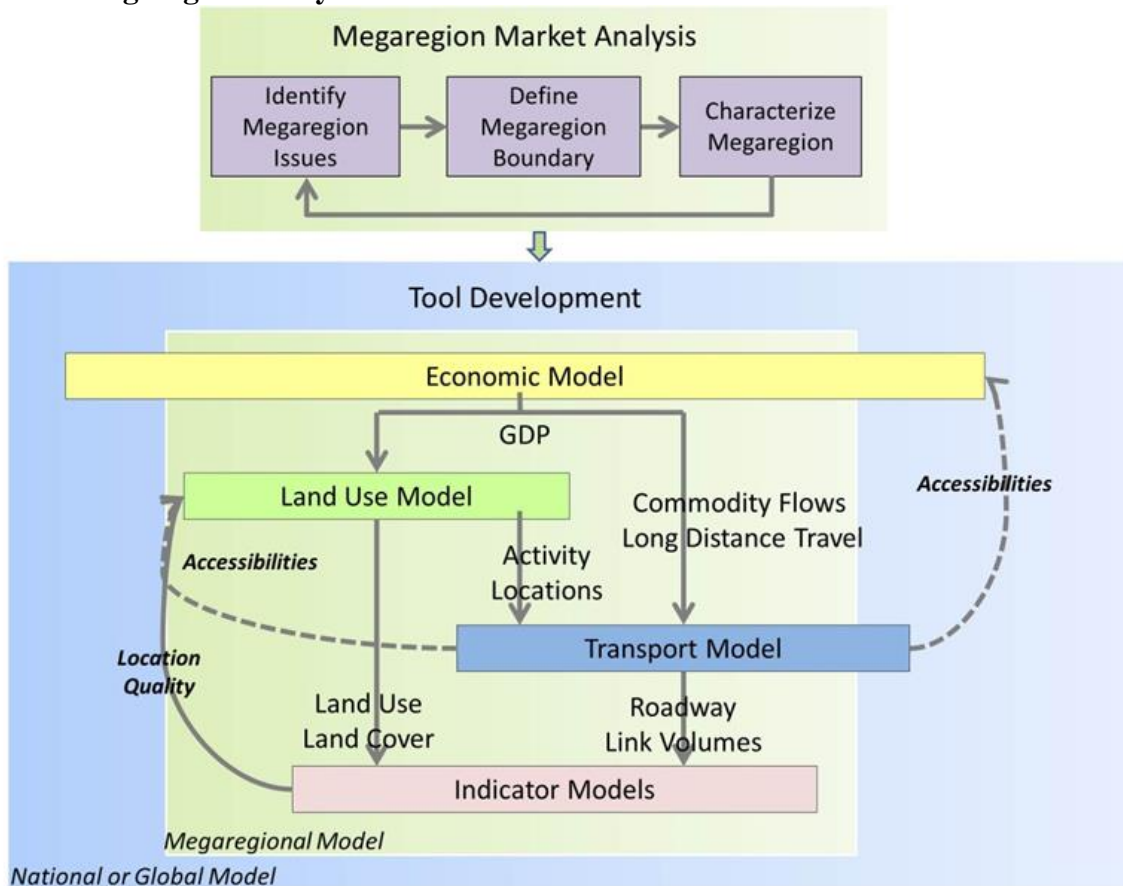
2.4.1. Market Analysis

The market analysis consists of three components: identifying the core issues, identifying the megaregion boundary, and characterizing the megaregion. These steps are interrelated. Depending on the circumstances, the market analysis may start with any of the three steps.

Identify Issues

Each megaregion is unique in terms of core issues that tie the megaregion together. The issue could be environmental, cultural, political or economic. For many megaregions, economic competitiveness is paramount, with transportation, land use, and the environment supporting a vibrant economy. Thus, a national economic model, as well as an analysis of key industry sectors should drive megaregion models and goods movement flows within the megaregional economy and linkages to the transportation system. The transportation needs of these economic flows provide a key input to decisions regarding new infrastructure investment at the megaregional level.

Identify Boundary

A megaregion's boundary may vary. It may be defined by environmental concerns, economy, cultural similarities or other considerations. For example, if the health of the Chesapeake Bay is of concern, the boundary could be defined by the Chesapeake Bay watershed. If the economy of the area surrounding the Bay is the issue, there would be a different boundary with attention to industrial chains. In some instances, a megaregion may be defined by political boundaries, with the megaregion addressing a number of issues.

Characterize Megaregion

The third step in the market analysis is to characterize the megaregion focusing on its most dominant issues. A two-tiered analysis is appropriate for megaregion characterization: first understanding the megaregion as an entity, identifying the relationship to other megaregions and the national/global economy, and then analyzing intramegaregion flows. The overall megaregional situation lays a foundation for detailed analysis. For example, as the backbone for megaregional economy, infrastructure reflects the spatial structure of a megaregion. In illustrating intramegaregion linkages, flow analysis works as an appropriate approach. By tracking various types of flows, such as people's flows, commodity flows, capital flows and information flows, as well as their origins and destination, one can better understand the industrial chain and economic hierarchy within a megaregion. Combined with the flow analysis, an analysis of infrastructure can help to understand whether the current capacity can adequately support projected changes in flows. When issues warrant and data exists, a forecast of future conditions can be added to the current analysis through a forecasting model or other tools.

2.4.2. Tool Development

In contrast to the analysis framework for typical transportation focused issues, the megaregion tool development is built on the economy. The economy is crucial in defining the region

geographically and its issues and metrics, and serves as a driver for activity locations and associated travel demands. A land use model becomes more important, as the location, options within the megaregion are interchangeable and coordinated policies can work towards efficiencies rather than competitions. Due to the larger geographic context, the framework must address longer distance travel for both people and freight. Indicator models are important measures of performance. Moreover, just as important as the individual model components are the data flows and feedbacks between them that reveal the complex interplay of forces. Probably most important is to tailor this framework to the policy questions of the particular megaregion.

Following, each module of the recommended framework is described in more detail.

Economic Models

Economic model (green in Figure 3). How might the economy change in the megaregion over the forecast period? For example, how might different industrial sectors change in terms of output and employment, both in general and under special conditions? How do transportation changes affect the megaregion economy? The economic model works at the national/global level, as growth in other parts of the world affect growth in the megaregion.

Economic data are typically generated and reported by political unit (country, state, county, etc.). But important economic interactions occur at geographies that are larger or smaller than political units, or at a scale comprising many smaller units. The notion of a megaregion, in contrast to conventional composite geographies such as metropolitan areas, is that even larger or more complex geographies may better represent the spatial dimension of the most successful integrated economies.

Additionally, all regional economies, even those of a megaregion, interact with other regions, the national economy, and even the international economy. This poses a challenge to a model charged with measuring the likely effects of policy changes such as improvements in the transportation infrastructure or changes in land-use policy. Representing a region as an isolated economic unit (when it is not) can lead to inaccurate measurement of the effects of policy initiatives on that megaregion because of failure to incorporate competitive or complementary interactions with other economic units.

National Economy

- Rationale – Captures the national economy influence on a megaregion's total population and employment (overall rise or fall, and economic productivity; especially if the region specializes in sectors that will change more than the economy on average).
- Scope – National/International, providing economic forecasts for the megaregion and/or sub-regions (e.g., states).
- Methods – Top-down approaches assume that the national economy influences the megaregion but that the influence of the megaregion on the national economy is minimal (e.g., Computable General Equilibrium models and Vector Auto-Regression models). The input–output components of these models may be used to examine flows between the megaregion and areas outside the megaregion.

- Data – National economic data such as energy prices, government spending, commodity prices or imports and exports.
- Sensitivities –Respond to economic variables such as wage tax rates, deficit spending, changes in productivity in other megaregions, or any other macroeconomic variables in their structure.
- Outputs – Population and employment (disaggregated by industrial sector) for the megaregion, possibly disaggregated to sub-regions.

Megaregion Economy

- Rationale – Interactions among sectors in the megaregion economy influence the megaregion's economic productivity. These interactions may be strengthened or weakened by changes in connectivity of the transportation system (accessibility).
- Scope – Megaregion level (and sub-areas within the megaregion), with allowance for flows to other megaregions.
- Methods –Input-output analysis to determine interactions between sectors, influenced by accessibility (from transport model). State of the Art economic models may have feedback between the megaregion model and the national economic model.
- Data –Input-Output inter-industry relationships and reliance on transport services. Data by employment sector, in the United States.
- Sensitivities/Output –Identification of where the megaregion economy can be strengthened by improving transportation linkages.
- Outputs – Changes in megaregion economy (e.g., Population and employment disaggregated by industrial sector). Advanced economic models may also make it possible to measure the gross megaregion product, with linkages to commodity flow and thus freight transportation.

Land Use Models

Land use model (green in Figure 3).Where is future growth of population and employment most likely to be located? Which part of the population is likely to relocate due to changes in job market, real-estate market and accessibilities?

A land use model must be able to allocate economic activities to zones, respond to changes in accessibility and cost, and provide sufficient detail on land cover changes to drive the environmental indicator models. The land-use model works at the megaregion level, as land-use changes outside the megaregion are largely irrelevant for this application.

- Rationale –Locations of population and employment provide origins and destinations for the transportation models. National as well as megaregional and local conditions affect the location of activities to model zones. The land-use model also needs to re-allocate activities among zones under changing local conditions.
- Scope – Annual; Statewide control totals allocated/re-allocated to model zones. Some models, particularly water quality models, may require data at the parcel or grid cell level.

- Methods – Allocation of megaregional control totals to model zones based on discrete choice theory or equilibrium-based input-output theory, sensitive to local development constraints and accessibility measures. State-of-the-art models would be sensitive to more generalized accessibility (time, cost, distance) and produce sufficient land use change details for air/water emissions models.
- Data – Historic and current land use data and land use development constraints (zoning). Survey to derive location preferences of households and employment.
- Sensitivities –Sensitive to accessibility and costs; sensitive to zoning and land use policies; indirectly influenced by sensitivities noted in the economic model.
- Outputs –Population and employment forecasts by model zone.

Travel Models

Travel models (blue in Figure 3). How many trips are made and where do they travel? Which modes of transport will be used based on congestion, pricing and available mode alternatives? Which route is chosen to reduce travel time? Travel demand is separated into long and short distance travel. Demand is then implemented at the relevant national/global or megaregion level. The assignment covers both layers, as some long distance trips (often defined as trips of 50 miles or more) may have their origin and destination within the megaregion.

There are multiple components to the travel demand model. Primarily, there is a core model, similar to a traditional MPO travel model that estimate short distance trips. Additionally, long term passenger and freight models need to be included. All trips within the meg-region are assigned to common networks by time of day.

Long Distance Freight Travel
- Rationale –Larger geography and policy issues of megaregions require a more comprehensive view of long distance freight movements. These trips are important to the megaregion's economic competitiveness, and account for growing share of congestion despite non-local drivers. The model should be able to test the impact of economic, land use, and transport policies on long distance freight movements. Such a model should be driven by national economic policies and include industry-commodity connection to be sensitive to input and output changes of different industries.
- Scope – Daily, National. Full US plus ports of entry. Multi-modal demand with multiple truck types.
- Methods – Multi-modal commodity flow input captures economic drivers and connects to zonal employment data; can limit assignment to trucks on roadway network; desirable to have truck/rail diversion rule set to respond to pricing. State-of-the-art models would provide full linkages of commodity flow from and freight accessibility feedback to the economic model; advanced methods may include tour-based or supply chain approaches.
- Data - Commodity flow patterns (e.g., FHWA Freight analysis Framework); production and consumption by commodity and industry; truck types by commodity; time-of-day distributions; network travel level of service.
- Sensitivities – Impact of economic policies, land use policies; pricing; truck-rail diversion and rail capacity limitations; other commodity-sensitive freight policies.

- Outputs – Modal flows by commodity, and truck trips by type, with one or both ends in the Megaregion model area.

Long Distance Person Travel (resident long distance + visitor travel)
- Rationale –As with freight, megaregions scope and policies require capturing local and multi-day travel of residents and visitors. A national perspective is required to capture competing destinations within and outside the megaregion.
- Scope – Daily, National. Full US plus key international destinations important to the megaregion. Multi-modal local demand including the modes auto, bus, rail, and air.
- Methods – Simulation based on surveys of long distance travel attributes (e.g., FHWA National Household Travel Survey or NHTS). State-of-the-art models would have full linkages of overall inter-megaregion travel demands driven by the economic model as well as feedback of travel accessibilities and attractions back to the economic model.
- Data – long distance travel survey dataset (e.g., NHTS); visitor survey; hotel beds or employees by zone; tourist attractions inventory; annual airport passenger demand; network travel level of service.
- Sensitivities – pricing (tolls, fuel price, and fares); local transit improvements, including high-speed rail.
- Outputs – Long distance person trips, domestic trips with specific origins and destinations, international trips with port of entry/exit.

Short Distance Commercial-Vehicle Travel
- Rationale –Captures local distribution of freight as well as service delivery for non-freight purposes.
- Scope – Peak and off-peak period traffic volumes; local and local truck trips that are internal to the megaregion of multiple truck types.
- Methods – Commonly a traditional 3-step model with trip generation, distribution and assignment. State-of-the-art models might include a tour-based model.
- Data – Establishment survey; truck counts; employment; time of day factors, network travel level of service.
- Sensitivities – pricing (tolls, fuel price), truck-only lanes, time of day congestion.
- Outputs – Truck trips by vehicle type within the megaregion.

Short Distance Person Travel Demand
- Rationale –Captures short distance person travel demand for all trip purposes. Urban transit is less detailed than in MPO models, especially if transit share is low.
- Scope – Peak and off-peak period traffic volumes; short distance person trips that are internal to the megaregion. Urban transit expected to only be reported at system-level or on local transit screen lines.
- Methods – Commonly a traditional 4-step model with trip generation, distribution, mode choice and assignment; simplified urban transit options (inputs and forecasting) particularly for bus. In a State-of-the-art model, a destination choice model replaces the trip distribution module and activity-based models could be applied to simulate tours rather than trips.

- Data – Household Travel Survey, transit system ridership, traffic counts, socio-economic zonal data (from the land use model), network travel level of service.
- Sensitivities – pricing (tolls, fuel price, and fares); network changes, urban transit improvements.
- Outputs – Person and vehicle trips by purpose within the megaregion.

Transport Supply/Time of Day
- Rationale – Required to assess congestion, vehicle and person miles travelled, and emissions. Time of day, if not explicit in demand models, captures peaking characteristics and associated congestion influence on travel behavior and activity allocation. Output accessibilities influence economic and land use models.
- Scope – Peak and off-peak periods that sum to daily travel; a subset of the long distance person and freight demand can be extracted and loaded on networks covering only the megaregion; multiple truck types, multiple drive-alone/shared-ride auto types. This typically will be limited to highway and transit assignments.
- Methods – Time of day factors from traffic counts and survey data. Multi-class equilibrium assignment. In a State-of-the-art model, long distance trips that cover multiple periods call for assignment in multiple periods or time dependent assignment methods.
- Data – Traffic count data by time of day; household travel survey; roadway network and link attributes; transit networks and transit service attributes; transit fares; trip tables to be assigned; tolls and other restrictions such as truck-only lanes; volume delay functions; passenger car equivalent values for trucks.
- Sensitivities – Network restrictions, such as bridges, tolls, network improvements, HOV lanes, or truck-only lanes.
- Outputs – Roadway link volumes, volume-to-capacity ratios, speeds; VMT by speed (for GHG emissions estimation); transit boarding's; network skims of distance, travel time, travel costs.

Indicator Models

Indicator models (pink in Figure 3).What are the likely impacts of policy scenarios on local emissions, such as noise or particular matter, global emissions in form of GHG emissions, and fiscal revenue and infrastructure costs? The megaregional level as where the necessary detail in land use and transportation is simulated.

Indicator models, based on particular policy issues to be addressed, may be included in the tools. Three examples of indicator odes are proposed. The indicator models are used to estimate specific impacts from various policies using outputs from the transportation, land-use and economic models. The results of the indicator models are typically not fed back to the other model components but may be used to identify additional scenarios to test, such as economic, land use, or transportation actions necessary to keep below targeted indicator values.

Air Emissions

- Rationale –Captures estimates of air emissions resulting from various policy changes using the EPA Motor Vehicle Emission Simulator (MOVES) model or other emission models.
- Scope – Adopts the boundary of the travel model assignment outputs.
- Methods – MOVES has been documented elsewhere. [4] Other simpler Department of Energy methods used in pre-MOVES applications can be employed, as warranted (e.g., for sketch level analysis, freight).
- Data –Trip tables, VMT, link volumes, and speeds (from the travel model) for running and cold start emissions; supplemental speed distribution data; local climactic conditions.
- Sensitivities – Respond to changes in travel demand, VMT and/or speeds.
- Outputs – Reports of megaregional quantities of various emissions.

Water Quality

- Rationale –Captures the impact of alternative policies on water quality. For example, a nutrient loading model forecasts the annual loads of nitrogen, phosphorus and sediments on the watershed.
- Scope – Covers the portion of the megaregion draining into major water bodies. In areas with outlets to multiple watersheds, a topographical model may be required.
- Methods – Coefficients by land use type estimate nutrient emissions.
- Data – Detailed ground classification for urban and agricultural land sub-classified into specific land cover categories. Changes to land use (from land use model)
- Sensitivities – The model responds to changes in land cover, and thus any economic, transport, or land use policy. Detailed parcel/grid-based land use model typically required to provide sufficient detail on land use change.
- Outputs – Estimated quantities of nutrient emissions produced by watershed.

Infrastructure Costs

- Rationale – Estimates state and local governments' costs to provide public infrastructure in support of new development (e.g., roads, sewer, and water).
- Scope – The model may be applied at any scale; ideally at the local jurisdiction level
- Methods – Established relationships between current development and the provision of infrastructure are applied to project future improvements needed to satisfy additional activity; assumes different levels of service for urban and rural areas. State-of-the-art models would apply locally, specific relationships rather than borrowed or national averages.
- Data – Residential development classified by housing type; existing water and road infrastructure and capacities. Property value trends, tax rates, etc.
- Sensitivities – Respond to economic, land use or transportation policies, which affect land use.
- Outputs – Public infrastructure costs and revenues of alternative land use patterns.

Model Component Options & Simulation Years

There are varieties of freely available and proprietary models and datasets that may be used to develop each component noted in the recommended framework. The most common options are listed below:

Economic
Exogenous/collaborative forecast, Computable General Equilibrium (CGE) models
Land use. Lowry-type model, micro-simulation models of household and firm location, economic allocation models

Transport
- Long distance freight. Models based on FHWA FAF[8] or TRANSEARCH datasets, supply chain models.
- Long distance passenger. Models based on NHTS or ATS[9] datasets
- Short distance freight. Trip-based or activity-based models, often using FHWA Quick Response Freight Manual.[10]
- Short distance passenger. Trip-based or activity-based models
- Assignment. Static assignment models or time dependent network models

Indicator
- Environmental. EPA MOVES (emissions)[11], Nutrient Loading (water quality), residential energy use.
- Fiscal. Customized tools written for local needs.

Emerging Methods
Multiple methods are emerging, which can enhance the models; INRIX data on speeds and volumes and OD data collected via GPS are two examples.

Commonly, a base year is simulated to validate the model and thereby demonstrate that results replicate observed conditions. Integrated models are often run in an evolutionary scheme, replicating the time-dependency of incremental changes in land use, socio-economic growth, and transport capacity improvements interactions over time. In these cases it is common to start with a base year in the past (e.g. 1990) and run the model iteratively to a current year for which data are available (e.g. 2008). If the model reproduces the trend to current conditions reasonably well, there is confidence that the model is capable of simulated future developments similarly well.

Policy scenarios are simulated for future years. Common forecast horizons reach 30 to 50 years into the future. In state-of-the-practice transportation-only models, only the base year and a forecast year are necessary to evaluate policy scenarios. In the integrated models proposed for megaregion analysis, an evolutionary forecast is more appropriate where intermediate years are simulated. To save runtime, the land-use model could be run every year, while the transportation

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[8] FHWA Freight Analysis Framework (http://ops.fhwa.dot.gov/freight/freight_analysis/faf/)
[9] FHWA National Household Travel Survey (NHTS) and pre-2000 American Travel Survey(ATS) (http://nhts.ornl.gov/
[10] FHWA Quick Response Freight Manual II (September 2007) (http://ops.fhwa.dot.gov/freight/publications/qrfm2/index.htm)
[11] US EPA MOVES model. (http://www.epa.gov/otaq/models/moves/index.htm).

model is updated only every five years, for example, since the aggregate changes in transport accessibility change slowly, while land use changes evolve in a time-dependent fashion over many years. Choice of intermediate years may depend on key changes in the forecast economic, land use, demographic conditions or transport capacity.

2.4.3. Data

Megaregional models require exogenous data for policy scenario inputs, establishing relationships, defining the infrastructure and the economy, and calibration. Additionally, data is exchanged endogenously among model components during model runs and output in performance metrics. Finally, output data presents a picture of activity within the megaregion and shows the results of policies under consideration.

The data discussion presented below shows the general data issues involved in any modeling effort and are not prescriptive to specific modeling efforts. Megaregions must carefully review available data, boundaries and policies to be addressed before determining final data requirements.

Exogenous Data

Exogenous data is used to develop inputs to the model and establish relationships critical to the methods of the component models. Exogenous data includes calibration data along with socio economic, infrastructure and policy data describing base year conditions.

Calibration Data

Calibration data sets parameters in the model and establishes behavioral relationships essential for the model. Calibration data allows the individual components of the model to operate and supports data flows between modules.

Model calibration is an art as well as a science, no more so than with integrated model. Integrated models prove more difficult to calibrate as they have many moving parts that must attempt to match many different observed target datasets. Often datasets from various economic, land use, transport sources are not consistent (e.g., the census identifies households where land cover indicates no residential uses) or were collected in different years, making it impossible to meet all model targets simultaneously. However since models covering a megaregion as large as a megaregion are most valuable in addressing strategic questions, relative magnitude and direction are more important than tight adherence to detailed calibration data. Sensitivity testing, discussed in some length in reference,[12] which evaluates whether the model provides reasonable responses to policy variables such as changes in land use or transportation conditions, should be the most valuable test of a model's capabilities.
Noted below are key exogenous datasets valuable for use in the many phases of model development and calibration: model estimation and calibration to observed behavior; model validation against an independent data set; and sensitivity testing of the model under changes in

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[12] Donnelly, R., Erhardt, G., Moeckel, R., Davidson, W. (2010) *Advanced Practices in Travel Forecasting.* National Cooperative Highway Research Program Synthesis 406. Washington: Transportation Research Board.

likely policy variables. The specific data needed will depend on model design, the types of issues to be addressed and the characteristics of the megaregion. Examples of calibration data include:

- Household Travel Survey (urban and rural).
- Traffic Count Data. Observed truck and auto by time period,
- On-Board transit survey (if transit use is significant)
- National Household Travel Survey (NHTS), American Travel Survey (ATS)
- FAF/Commodity flow survey
- Census data, American Community Survey (ACS)
- Highway Performance Monitoring System (HPMS)
- Regional Household Travel Survey (HTS)
- Stated preference surveys
- Visitor data & surveys
- Land and/or floor space price data
- Special generator studies
- Establishment survey
- Truck intercept Origin-Destination surveys

Socio Economic, Infrastructure and Policy Data

Socio Economic data describes the current condition of the economy and the location of population and employment. Infrastructure data describes the current conditions with respect to the network including the number of lanes on each highway link and the location and frequency of transit service. Policy data represents inputs modifiable by the user as policy levers, imposed in a scenario in order to evaluate the mega-regional impacts. These result from a specific policy action or anticipating variation in global/national conditions.

Examples of this type of data include:
- Multi-modal network, economic and socio demographic conditions
- Network restrictions
- Zoning/ development restrictions/subsidies;
- Land consumption by sector
  Location of population and employment (e.g., Census data, American Communities Survey (ACS), Bureau of Labor Statistics (BLS) data)
- Anticipated policies affecting networks, the economy and land development
Economic forecasts (e.g., recession, energy cost), industry mix, technologies (e.g., shift to local consumption)

Endogenous Data Flows

Data flows between components from the top of the model chain to the bottom (economic-land use-transport-indicators) are substantial. More difficult from a modeling perspective are data flows that feedback or push up the model change. Feedback flows is critical between the network travel level of service and the demand models. Where significant changes in accessibility occur

they will also affect the land use and economic models. The use of feedback shall be driven by mega-region policies and performance measures of interest (Figure 4).

Figure 4 Endogenous Data Flows
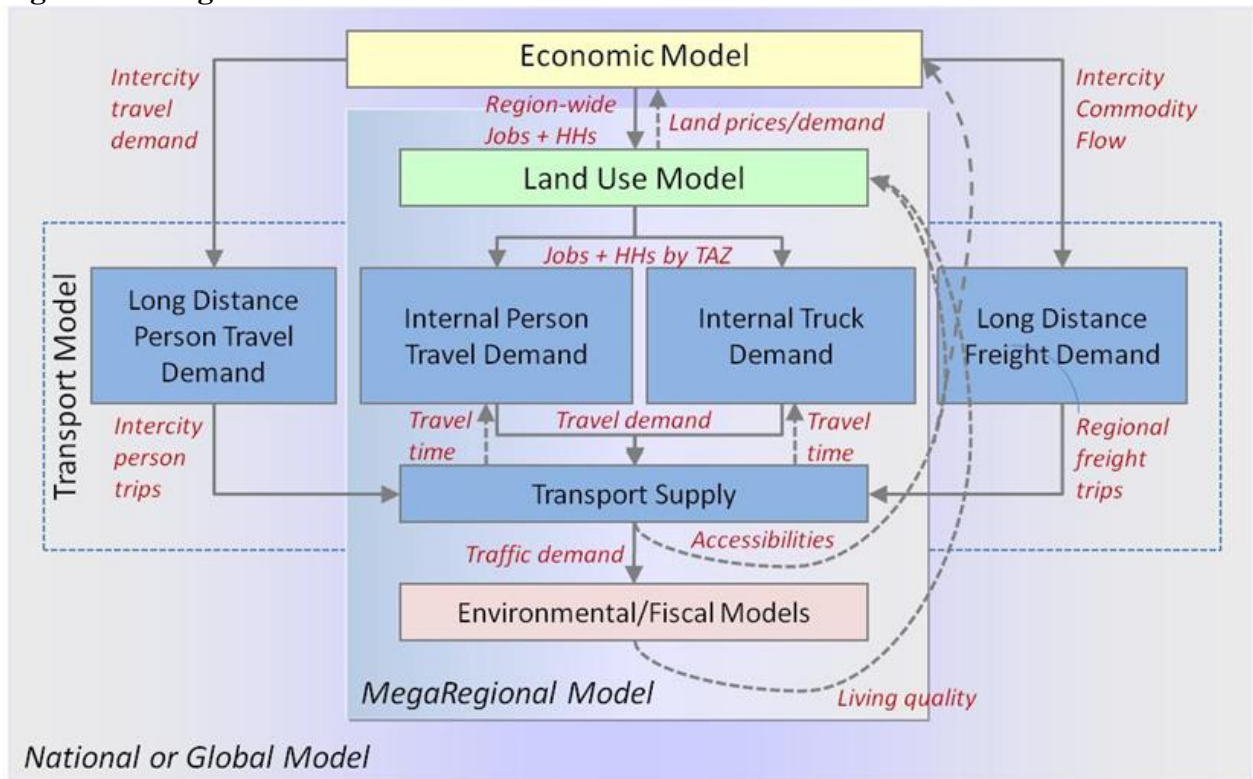
Output Data

Output data represents the results of the model runs and presents a picture of what conditions are likely to be under various policies. The output measures presented will depend on the structure of the model used and the questions which the modeler or policy maker desires to answer. Examples of output measures are listed below:

Transportation
- Vehicle-miles traveled (VMT), vehicle-hours traveled (VHT), vehicle-hours delay (VHD)
- Volumes on selected links, such as major interstate highways, bridges, or other bottleneck links
- Transit ridership
- Point to point travel times
- Location of congestion
- Average trip length

Land use
- Location of employment

- Location of population
- Land cover
- Land prices

*Economic*
- Economic flows
- Freight flows
- Employment growth

Environmental
- Air quality
- Water quality

2.4.4. Integration

Megaregion models should relate both to national models (at a more aggregate level) and with state and MPO models (at a more disaggregate level). This integration should be bi-directional, with megaregion models utilizing information from other models and megaregion models providing information to other models.

Figure 5 Two Dimensions of Model Integration
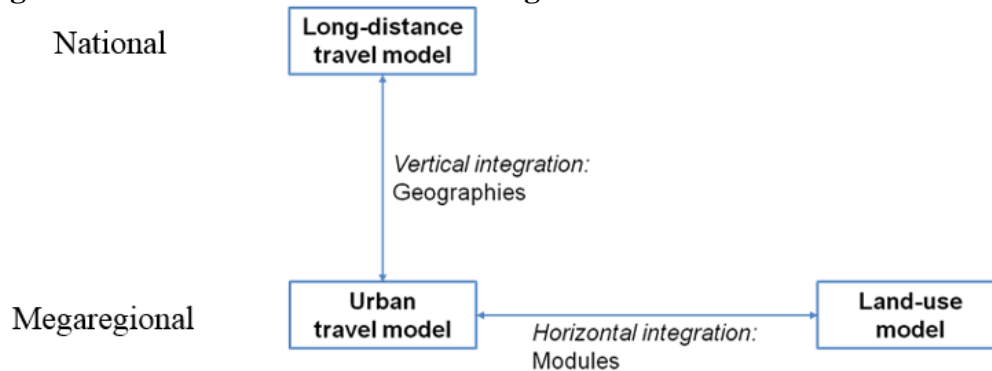
Vertical Integration across Geographies

Integrating a national with a megaregional model requires close integration of modules to pass on data required by each model, avoid double counting of aspects simulating, and develop smooth interfaces that facilitate integration even under extreme scenarios, as shown in Figure 5.

Building modules that work at different geographies allows simulating similar tasks (such as person trips) with different modeling approaches catered to each level. Each module may be designed differently, and the spatial resolution of different modules may differ to fit each model's purpose. For example, while a destination choice model works well to distribute person trips at the local level, this module becomes difficult to apply with both short distance and long distance trips using the same calibration results. Thus, the same task of a person trip may be simulated with different methods at the local and the megaregional level. The spatial resolution may be

finer at the local level and much coarser at the megaregional level. For a trip that stays within the study area, the detailed locations of origin and destination are of interest. For a trip that leaves the study area to a destination a hundred miles away, the precise location of the destination may not be irrelevant. While a geographic distinction in different model layers most likely is less relevant for urban models, this distinction is helpful when modeling larger study areas, such as a megaregion.

If trips are simulated at several geographic layers, special attention has to be given to minimize inconsistencies at the border between the layers. If the megaregional model has very small zones, and the national model had very large zones as spatial representation, pathological behavior may be generated at the border. While outside the megaregion the model may only generate trips between zonal centroids that are fairly far apart, the model finds centroids that are close together inside the megaregion. This may lead to different trip length frequency distributions that are solely caused by the different resolutions in the zone system inside and outside the megaregion. One way to overcome this inconsistency is by applying separate models to the more detailed megaregional zone system than are used with the coarser zone system at the national level. This way, each component can be calibrated to its respective zonal resolution, creating a more consistent trip length frequency distribution.

Horizontal Integration across Modules

At the same geographic layer, a series of model components need to be integrated horizontally, including an economic model, a land use model, a person-travel demand model, a truck model, and several environmental impact models. Every model is likely to benefit from (if not require) an integration with some or all other models. Figure 6 shows graphically an example integration of modules at the same level of geography.

Figure 6 Horizontal Integration of Modules
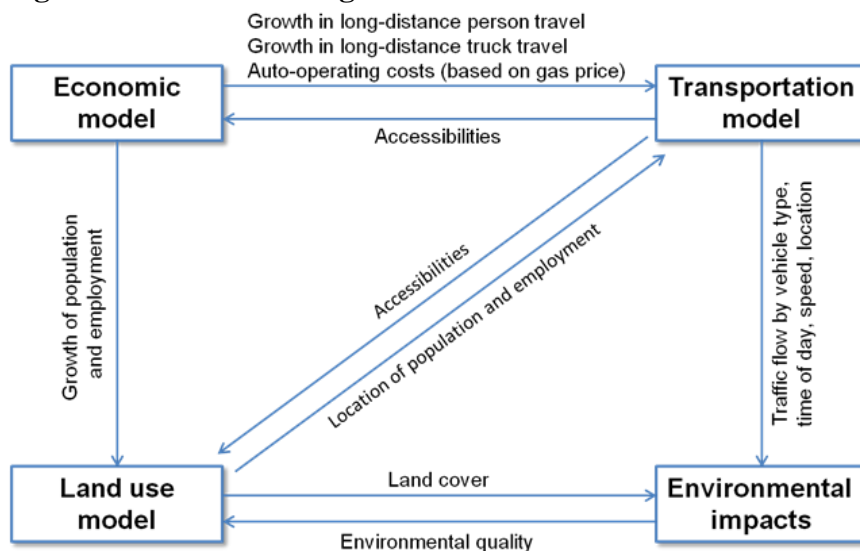
Source: Chesapeake Megaregion Model

In the figure, the economic model provides population and employment for the land-use model based exogenously given overall growth. At this point, the economic model provides these data

at the state level, and the land-use model allocates population and employment to the zonal level within these statewide constraints (or the economic model could provide the socio-economic control totals for the entire study are of the CM model, allowing the land-use model to distribution population and employment entirely based on utilities of different locations, unconstrained by artificial state borders). The economic model also sets the stage for the transportation model, as it defines growth in long distance person travel, long distance truck travel and auto-operating costs based on exogenously given energy prices. The transportation model returns accessibilities to both the economic model and the land-use model. Accessibilities are considered to be one variable in predicting economic growth as well as the attractiveness of locations for households and firms to locate.

To calculate environmental impacts, the transportation model provides traffic volumes by vehicle type, time of day and speed at the link level. The land-use model provides land cover to the environmental impacts module, as different land cover types have different impacts on run-off water, fixed-source emissions and infrastructure costs. The environmental model could also provide feedback to the land-use model on environmental quality. Environmental quality is a relevant location factor, as households enjoy living close to well-kept environmental amenities such as parks and shorelines, and away from highways and other sources of noise or pollution.

Integration and Coordination with Other Models

Megaregion models by their scope are most valuable in assessing strategic megaregion-wide policy actions, and should not try to replicate the urban-level forecasts best left to MPO models, they are also not encumbered by the political boundaries of statewide transport models that miss key economic connections across state borders and often limit their view to transportation issues. The broad megaregion view that sees other megaregions as global competitors also benefits from linkages with national models.

Combining Existing Models

From MPO/DOT models, the megaregion models can use data (e.g., household and employment data, household survey, transit surveys, networks, traffic counts and screenlines) and in certain circumstances utilize these models directly. A few possible approaches are shown in Figure 7.

Figure 7 MPO/DOT Model Integration Options
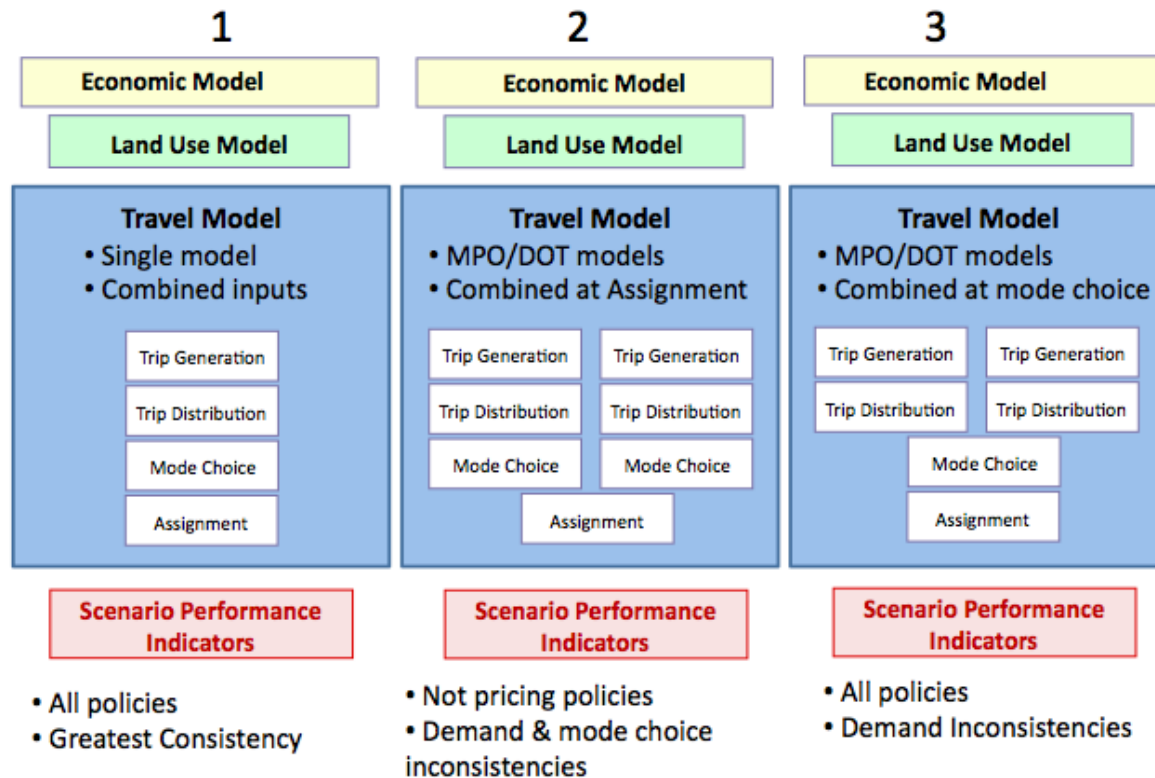
Option 1 shows a situation where a new megaregion model is developed, borrowing inputs and potentially model components from other models and applying them to the full megaregion. This enables the greatest consistency within the megaregion model components and the greatest flexibility in which policies the model can be built to address.

Options 2 and 3 show hybrid approaches where existing state or urban models might be run on their own with results combined either at the mode choice (OD tables) and/or assignment (vehicular trip tables) steps. Pricing and transit scenarios may require consistent megaregion modeling of mode choice. Although these hybrid options entail some inconsistencies, they likely can be developed more quickly, depending upon the scenario of interest.

In all cases, a reconciliation process between the megaregion model and other models can establish consistent inputs (e.g., socio-economic data, networks), model assumptions and temper unrealistic forecasts across the megaregion's models. The reconciliation process also supports 'buy in' by local agencies and provides for further use of the megaregion model.

Information may also be shared from the megaregion models to the MPO or state model with the megaregion model providing improved understanding of external flows (inbound, outbound, and through) for local analytic efforts. The megaregion models can also provide a national economic model with better estimates of megaregion economic activity under various scenarios.

Integration with National Models

In developing the megaregion model, careful attention must be paid to the relationship between the megaregion and the national economy and the megaregion and the nation transportation network.

The national economy is critical to estimating employment and population in the megaregion and the overall economic health of the megaregion. If the megaregion relies on a particular economic sector for most of its employment, a change in that sector can have major impacts, which ricochet through the model chain. A megaregion may also play a key role in the national economy and   what happens in the megaregion can affect the rest of the country.

The national transportation system can also play a major role, not only in transportation within the megaregion but also in the megaregion economy. External trips can play a major factor in traffic congestion within the megaregion, not only affecting the flow of traffic but also, affecting the flow of freight. In addition to affecting traffic movements, significant changes to the national transportation network can affect the megaregion economy. For example, the Panama Canal is currently being widened to allow deep draft vessels to pass through. This will influence traffic in east and west coast ports and, with additional shipping capability, affect the economy in areas served by those ports.

Multi-Scale Evaluation

By integrating the megaregion models with national and metropolitan level models the framework provides for a multi- level analysis, tying together all aspects of the megaregion. A new project can be evaluated based on its ability to move traffic through an urban area, how it supports the nationwide movement of freight and how it supports the development of the megaregion economy. This interaction also allows the framework to analyze the combined effects of policies in multiple sates and urban areas within the megaregion.

The framework also supports addressing economic and transportation issues in rural areas; although due to the high-level view in megaregion models, additional analysis at greater detail should be conducted when specific rural questions are addressed.

Implementation

A theoretically defensible framework for megaregional analysis was presented in Sections 1-4 of this document. However, implementation may vary depending upon megaregional data, existing tools, and policy issues of interest. Additionally, any framework implementation will require data collection, and outreach to local institutions to be successful. This section discusses these implementation topics in tailoring the generalized framework.

2.4.5. Framework Evolution

The market analysis and associated identification of megaregion specific issues will indicate what capabilities the model should strive for to best serve the megaregion's interests. However,

funding limitations will typically preclude the full vision from being implemented immediately. Instead, it is recommended that a multi-year vision/development plan be established at this point with milestones and associated criteria for success. This not only establishes the vision and feasible steps to reach it, but it also affords an opportunity to engage stakeholders and decisions-makers in a common understanding of analysis benefits, desired performance measures, data needs, and allows long term planning to capture funding opportunities. The multi-year roadmap should recognize that individual model components might take different approaches than the generalized recommended framework due to megaregional data, tools, and policy issues of interest.

A staged approach implies compromises, but provides a tool that is able to bring value in a short time to assist policy decisions, while making the case for continued investment in long term improvement of analysis fidelity. Initial steps may involve the following compromises:

Evolutionary Approach. Initial components may serve as placeholders with enhanced functionality evolving with the megaregion's scenarios of interest. In some cases, full functionality may never be required (e.g., sophisticated mode choice models are likely not to be required where no viable transit alternative exists).

Minimum Requirements. Identify initial desired performance measures and issues then work backwards to identify model capabilities to output them. Identify initial desired policies and build just enough to capture their integrated impacts. In computer science, this approach is called the 'Agile' paradigm. It starts with simplest model possible and continually evolves (instead of the big design up front). This provides intermediate tools to show value.

Feedbacks. It is easiest to travel down the model chain from national economics allocated to zones that drive travel and impacts. Feedback up the model chain is more difficult, such as the impacts on the economy size and location changes from accessibility changes and travel costs. Such feedback mechanisms may not be fully functional in initial capabilities.

Data Collection. In some cases, additional data collection is needed to build a tool with the required functionality. For example, surveys may be required to understand the sensitivity of travelers to a new high-speed passenger rail service relative to existing modal options. As such, simpler or borrowed models maybe put in place until the additional data is obtained.

2.4.6. Other Implementation Issues

Other factors important to all aspects of implementation include the following:

Data Collection. Is the data readily available, are there any proprietary issues, are local sources available, and can data from multiple sources be easily merged? How is megaregion data reconciled with MPO or statewide data and with national data?

Network and Zone Detail. The level of detail in the network affects the implementation. Decisions must be made on which roadway functional classes will be modeled, how transit will be represented and the zone size. In general the more detailed the network and zone system the

more accurate the model. At the same time the data collection costs and run times and model development cost increase, often significantly, with the level of detail. If transit is a major factor, there should be sufficient detail to capture the effects of transit. The level of detail must also be weighed against the policy questions being addressed.

Outreach. Outreach to local and state governments is critical to the successful use of the model. Outreach supports the integration of the megaregion model with other decision tools and provides feedback for improvement of the model. Outreach will also support the sharing of data and experience.

Resources. Staffing to run and maintain the model will be required. In addition to training staff, training should also be provided to others such as MPO staff or state DOT staff who may have an interest in using the model. Funding will be required to support ongoing maintenance of the model and updating of data.

Peer Review. Effective use of an external Peer Review panel can pay high dividends. Such a panel can oversee the project over its lifespan, playing a key role in model design and acceptance. A good point for engaging a peer review is after issues and goals have been established, and initial model capabilities have been demonstrated. At this point, a panel can help prioritize future evolutionary development to meet the megaregions evolving policy issues. Membership on the panel should be focused primarily on leading practitioners in the field of statewide travel demand modeling. The FHWA has a program to support facilitating and funding peer reviews.

Table 1 Framework Implementation of Various Megaregion Issues

Policy/Action	Required Model Capabilities			Required Data	Comments
	Economic	Land Use	Transportation		
Transportation					
High-speed Rail (or other long distance high-speed transport)	National economic model of long distance travel demand	Accessibility impacts to location choice. (Feedback)	Long distance Mode Choice model sensitive to time, cost and price and includes air travel	Rail station /airport locations, service frequency and costs Networks fully code mode access times (e.g., time between airport/train station and final destination).	Expect denser land use near rail stations
Freight Movement (Freight road/rail expressways; truck only lanes)	Potential productivity gains due to reduced transport costs. (Feedback)		Freight mode selection to estimate change in usage, modified assignment routines	Location/attributes of additional freight links	
Freight Coordination (Improved linkage between ports and networks; highway and/or rail; port expansion)	Economic change if significant effect on global/national shipping routes			Network changes near ports, modification to highway or rail links	May be some change in industry activity at locations of improved access.
Pricing/Tolls (Coordinated Tolls, congestion pricing, VMT fees, operations improvements)		Accessibility impacts to location choice, depending on magnitude of pricing/toll. (Feedback)	Trip Generation rates adjusted for trip suppression and/or trip chaining Mode Choice toll nest and market stratification to capture different values of time Enhanced time of day choice model and route choice in assignment, sensitive to tolls. Include reliability in freight assignment	Magnitude of pricing, location of tolls	Impact on land use larger and more complex with area or cordon pricing Freight can be assumed to pass costs onto customers with some exception for selected commodities over a certain trip length.
Emergency response (Short and Long Term)				Network restrictions/ enhancements to support emergency response (short term) Changes in land use and network based on nature of emergency event (long term)	*Short term Example:* 9/11 or immediate response to Katrina *Long term example:* Long term impact of Katrina

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Economic					
Growth and Productivity (employment diversification, local production/consumption, major employer changes)	Assess transportation linkages between economic sectors and resulting multipliers			National and local population and employment forecasts.	Employment location by sector may be needed to assess economic linkages
Subsidies/Incentives (regional coordination at firm- and industry-level)	Modify economic forecast based on regional/sub-regional economic change			Location of zoning	
Workforce/Job Training	Economic forecast (GSP, employment, population) sensitive to income mix			Population forecast by income and location	Could use exogenous forecasts (GSP, employment, & population)
Industry Clustering (Industries agglomerate to one area of megaregion or leave megaregion)	Economic forecast sensitive to inter-industry relationships (e.g., Input/output table)	Employment location decisions sensitive to inter-industry relationships. Sensitivity to jobs-housing balance by income	Freight model sensitive to inter-industry commodity flow relationships	Revised economic forecast representing clustered Industry. Zoning policies if clustering supported by zoning	
Land Use					
Growth management	Growth management measures may affect land prices.	Location decisions sensitive to land use constraints		Zoning policies	Need detailed land use model to analyze growth management
Indicators					
Eco-system (nutrient loading, habitat preservation; resource management)		Forecast change in land cover at detail sufficient for indicator models.		Land use restrictions to preserve habitat	Megaregion & Ecosystem boundaries not always consistent; Nutrient loading changes with land cover
Air Emissions (Climate change, GHG Emissions)			Typical application of MOVES Micro-simulation Assignment or Speed adjustments	Emissions rates derived from MOVES	
Fiscal Impact (public infrastructure costs, toll revenues)		Must locate sufficient detail on population, employment, school age children	Tabulation of use of toll facilities sufficient to estimate revenues (e.g., by time of day and vehicle type)		

3. MEGAREGION CASE STUDY

To test the concepts recommended in earlier sections of this report, a case study was performed as a proof of concept. The goal of the case study was to exercise an analytical framework following these guidelines to test its usefulness to a hypothetical Megaregion governing body in addressing the investment and policy questions posed in a U.S. megaregion. The Chesapeake Megaregion, the southern end of the larger Eastern Seaboard Megapolis was chosen, due to the advanced nature of analysis tools in this megaregion. These tools, already largely customized to the needs of the megaregion, were modified along the lines of the recommended analysis framework and expanded to cover the geographic extent of the megaregion. Initial case study efforts involved an investigation to better understand and characterize the megaregion, the inter-related sub-regions, trends and common issues. Of the issues of importance to the megaregion, resilience of the Chesapeake Megaregion to a High Energy Price future was the chosen for analysis, a topic of interest to all U.S. megaregions. A likely policy response by the megaregion board to the scenario findings, highlighting the megaregion view concludes the section. The analysis framework now in place is well positioned to further test such chosen policies, including the value of coordinated policy responses.

This section begins with a market analysis of the Chesapeake Megaregion, followed by the development and application of an analytic tool, and the potential response from a megaregion board.

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4. MARKET ANALYSIS – CHESAPEAKE MEGAREGION

In the report "Megaregions: Delineating Existing and Emerging Megaregions", Ross provides a comprehensive methodology for defining and delineating megaregions. Using available data from multiple sources including the Highway Performance Monitoring System (HPMS), the Freight Analysis Framework (FAF), Census, Woods and Poole, and private data sources, she first identified megaregion core areas, areas of influence, and clusters of metropolitan regions. Through applying analytic techniques including Graph Theory, Markov chains and factor analysis,[13] megaregions in the United States were identified.

One of the megaregions described by Ross is the Washington D.C – Virginia megaregion. Ross finds that interactions within the Buffalo-Boston-New York-Philadelphia megaregion and the Washington DC-Virginia megaregion are stronger than between these two megaregions. This smaller geography also makes policy implementation more feasible, given that collaborative policy solutions require cooperation among a smaller number of states and local governments. As described in section 5, Boundary, this area was expanded and redefined as the Chesapeake Megaregion.

In the following sections, the megaregion analysis framework developed above is applied. The economy and transportation are shown to be key issues within this megaregion in Chapter 4. Chapter 5 defines the boundary expanded beyond that provided by Ross to include additional critical areas as well as to apply available data analysis tools. A detailed characterization is made in Chapter 6.

4.1. ISSUES

The Chesapeake Megaregion forms around its primary environmental resource--the Chesapeake Bay. It is comprised of an advanced system of rail, ports, and highways that link labor markets and facilitate commodity flows, and linked labor markets that depend heavily on the transportation and government sectors. The Chesapeake Megaregion is projected to grow the fastest among all other megaregions within the Northeast Corridor, giving rise to a range of growth-related policy challenges including traffic congestion and environmental pollution.[14] The widening of the Panama Canal may redirect a portion of international freight flows to the megaregion's major ports of Norfolk and Baltimore. Existing political linkages also support the concept of Chesapeake Megaregion. Examples of these linkages include the I-95 Corridor Coalition that tackles freight movement and the Chesapeake Commission which addresses stewardship of the Bay, the unifying economic and environmental heart of the megaregion.[15][16]

Common issues in the megaregion include congestion and various discussions on congestion pricing solutions, growth in port traffic, land use planning to balance urban and agricultural

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[13] Ross. 2008. Literature Review of the Implications for U.S. Infrastructure Investment and Transportation Planning.
[14] Lang and Nelson. 2007 Lang, Robert E. and Arthur C. Nelson. 2007. The Rise of the Megapolitans. Planning (January): 7-12.
[15] http://www.chesbay.us/
[16] http://www.i95coalition.org/i95/Default.aspx

interests, and environmental concerns about Bay water quality and sea level rise due to global climate change. In addition, like most areas in the United States, the economy is a major issue and actions to promote or support economic development are a major concern.

While there are multiple issues in the Chesapeake Megaregion, with current conditions in the United States, all megaregions are concerned about the economy and economic development. This case study focuses on the economy and transportation within the Chesapeake Megaregion.

4.2. BOUNDARY

While Ross has provided an initial definition of the Washington D.C. – Virginia megaregion borders, to fully understand what is occurring in this area require an expansion of the boundary to capture the interactions with surrounding areas and the development of necessary tools to analyze flows within the megaregion. This expanded area is referred to as the Chesapeake Megaregion. The northern borders were expanded to encompass southern Pennsylvania and the eastern borders extended to encompass Northern Delaware and Wilmington, both areas which interact with the Washington DC – Virginia economy.

In defining the boundary, the availability of analytic tool was considered. Previously the study team had developed the Maryland Statewide Transportation Model (MSTM) for the Maryland State Highway Administration. This model covered most of the area identified in the Ross report plus the Southern Pennsylvania and Wilmington, Delaware areas. As said above, these are key areas to understanding the economic and transportation issues and should be included. The MSTM coverage area had significant overlap with the Ross definition so the two areas were combined. Combining these two delineations provided for an increased analytic capability and an improved understanding of the megaregion.

Figure 8 to Figure 10 illustrate the steps in the development of the Chesapeake Megaregion area.

Figure 8 illustrates the Washington DC – Virginia megaregion as defined by Ross. The area includes most of Maryland, the eastern portion of Virginia, and a portion of the Delmarva Peninsula (The area between the Chesapeake Bay and Atlantic Ocean containing portions of Delaware, Maryland and Virginia).

Figure 9 shows the coverage area of the MSTM, including southern Pennsylvania, northern Delaware. It also includes western Maryland and Northeast West Virginia. These areas are needed to fully understand Chesapeake Megaregion boundary conditions.

Figure 10 combines the addition of the MSTM area to the Ross areas and adds rural areas necessary to smooth the boundary for model development. In Figure 10 the Ross definition is shown in the maroon area, the portions added by the MSTM in red and the orange areas were added in to ensure boundary conditions were properly represented for modeling purposes.

Figure 8 Ross' Map of the Washington DC-Virginia Megaregion
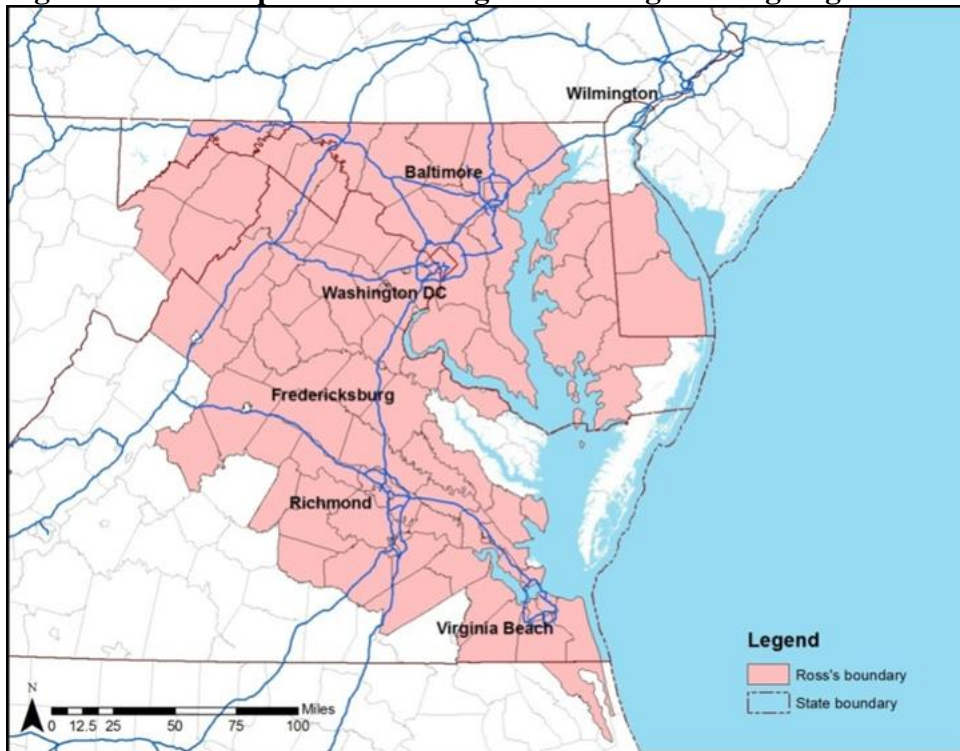

Source: Ross, Cathorine. DC-Virginia Megaregion [facsimile]. "Literature Review of Organizational Structures and Finance of Multi-jurisdictional Initiatives and the Implications for Megaregion Transportation Planning in the U.S.." 2011. <http://www.fhwa.dot.gov/planning/publications/megaregions_report_2012/megaregions2012.pdf>. Reproduce.

Figure 9 Maryland State Transportation Model Coverage Area
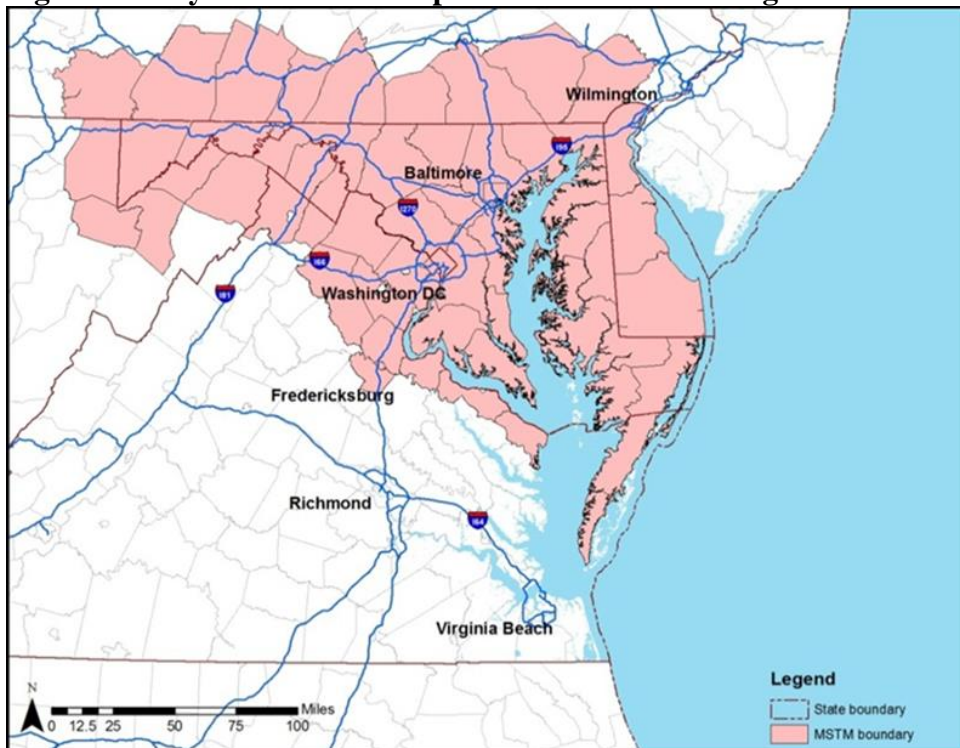

Source: Center for Smart Growth Research and Education. Maryland State Transportation Model Coverage Area.

Figure 10 Development of Chesapeake Megaregion Modeling Area
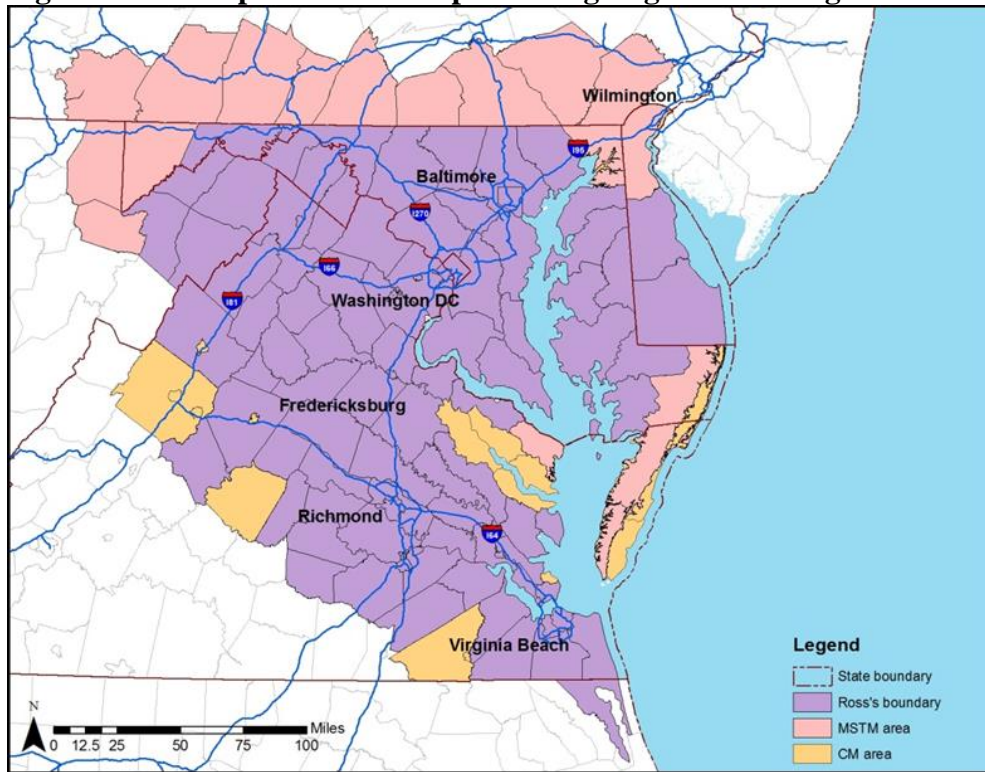
The Chesapeake Megaregion contains 142 counties or county equivalents. Within the megaregion there are 12 MPOs including the Metropolitan Washington Council of Governments, the Baltimore Metropolitan Council, the Cumberland Area MPO, the Hagerstown Area MPO, the Salisbury Maryland/Delaware MPO, The St. Charles Maryland MPO, the Charlottesville-Albemarle MPO, the Fredericksburg Area MPO, the Hampton Roads Planning Organization, the Richmond Area MPO, the Winchester Frederick MPO and the Wilmington Area Planning Council. The megaregion also contains areas not part of an MPO. For illustration purposes the counties have been aggregated into 17 subregions, as shown in Figure 11.

Figure 11 Subregions in the Chesapeake Megaregion
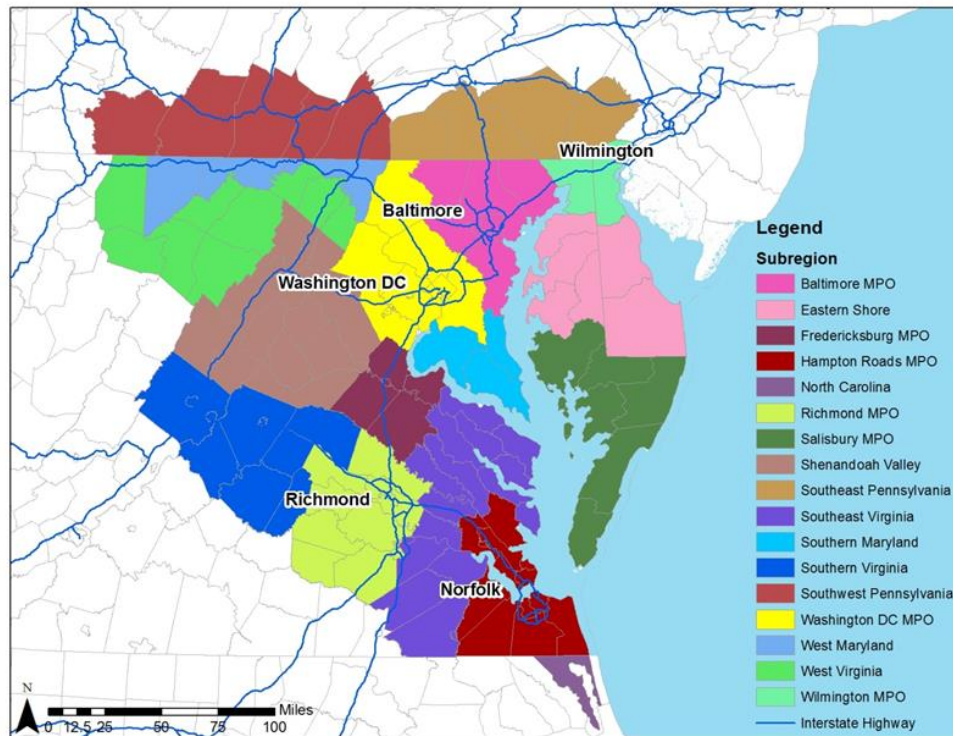
4.3.   CHARACTERIZATION

4.3.1. Data

The primary data sources used to characterize the Chesapeake Megaregion include (1) Freight Analysis Framework 3.3, (2) American Community Survey 2006-2008 three-year estimate, and (3) 2009 IMPLAN data.

Freight Analysis Framework (FAF)

FAF data illustrates the freight flows between the Chesapeake Megaregion and other major metropolitan areas and states by all modes of transportation. The third generation of the FAF data, called FAF[3], was released in summer 2010 and contains flows between 123 domestic FAF zones and 8 international FAF regions. FAF[3] data provide commodity flows in tons and dollars by:

- FAF zones (123 domestic + 8 international zones)
- Mode (7 types: Truck, Rail, Water, Air, Multiple modes & mail, Pipeline, Other & unknown)
- Standard Classification of Transported Goods (SCTG) commodity (43 types)
- Port of entry/exit for international flows (i.e. border crossing, marine port or airport)

The base year is 2007, and freight flow forecasts are provided for the years 2015 to 2040 in five-year increments. At the time of the implementation of this model, the most recent version of FAF3 was 3.3.[17]

Figure 12 illustrates the FAF zones in the CM. The zones in tan are contained wholly within the Chesapeake Megaregion; the zones in yellow partially within the Chesapeake Megaregion, and zones in blue are external. The following are definitions of the zones: (1) MD Balt – Maryland, Baltimore area, (2) MD Washi – Maryland, area around Washington, (3) MD Rem – Remainder of Maryland, (4) VA Washi – Virginia, Washington area, (5) VA Richm – Virginia, Richmond area, (6) VA Virgi – Virginia, Norfolk and Virginia Beach, (7) DC Washi – Washington, DC, and (8) DE – Delaware.

Figure 12 Map of FAF Zones within the Chesapeake Megaregion
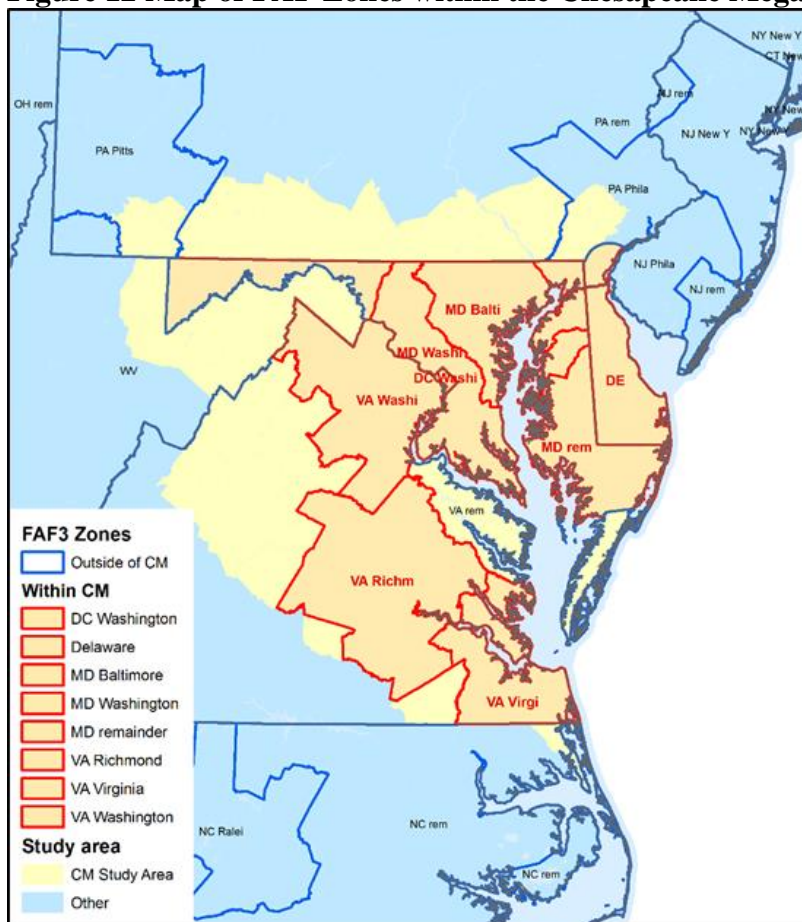
Source: FAF 3.3

American Community Survey (ACS)

The American Community Survey is an ongoing sample survey by the Census Bureau to collect the information for planning investments and services. The ACS is conducted annually and data

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[17] http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/

is released at three and five year intervals The ACS data used in this market analysis is the 2006-2008 3-year estimate.[18]

IMPLAN

To illustrate economic linkages, data from IMPLAN was used. The IMPLAN data contains information on dollar flows between each county pair within the Chesapeake Megaregion. The dollar flows are classified by 440 sectors in both the originating county and the receiving county. Thus, each county pair has 440x440 data points.
For the economic flows analysis, only highway freight flows were considered. In order to develop the inter-county highway freight flows HaulChoice, a proprietary model developed by ECONorthwest, was used. HaulChoice is a freight mode-choice model that predicts surface transportation mode choice by commodity class. It provides these forecasts by a subset of IMPLAN sectors.

Haul Choice uses proprietary mathematical and statistical procedures, as well as its own crosswalks between NAICS and IMPLAN commodity categories The model uses characteristics of zonal endpoints, the haul distance and cost, and certain megaregional controls to parameterize the mode choice model. The model first identifies which financial flows include physical movement of goods, then converts those movements by dollar value into tonnage. The end product of the HaulChoice model is truck tonnage by county pair and the dollar value of truck tonnage by county pair. Due to budgetary limitations, IMPLAN data could only be obtained for the District of Columbia, Delaware, Maryland and Virginia.[19]

4.3.2. Background

Infrastructure

The Chesapeake Megaregion contains major air, maritime, rail and highway facilities, which provide external linkages to the rest of the nation and the world and also support internal flows of freight and people, as shown in Figure 13.

Three major airports serve the Chesapeake Megaregion, Baltimore Washington International (BWI), Dulles and Ronald Reagan. Collectively they account for more than 31 million enplanements annually. Dulles and BWI are major international hubs as well as serving as transfer points for domestic air travel.[20] Washington Reagan Airport links to most of the east coast. Major port facilities include Baltimore and the Hampton Roads, accounting for a large volume of ocean going trade. Baltimore handles 40 million tons of trade per year. Hampton Roads, handling 62 million tons per year, ranks eighth nationally and is second only to the New York area in moving tonnage on the east coast. Baltimore handles 40 million tons per year and

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[18] http://www.census.gov/acs/www/
[19] Note: The estimates produced by IMPLAN and HaulChoice differ from other data bases such as FAF and TranSearch. The IMPLAN data focuses on estimating the intercounty dollar flows, and then derives tonnage from these flows. FAF, for example, divides the country into FAF zones then develops interzonal tonnages from various data sources. If the analytic need is to get national movements correct, the FAF would be a better tool. If the need is to understand the intercounty economics, IMPLAN would be the better tool.
[20] Federal Aviation Administration, 2011

ranks 16th nationally in terms of tons handled. The widening of the Panama Canal, with the potential for more deep draft ships landing at east coast ports, will affect the Chesapeake Megaregion seaborne traffic. While Hampton Roads can handle more traffic, Baltimore has landside access problems and must expand the landside transportation facilities, which provide access to the port.[21]

The surface transportation linkages include 13,000 lane miles of Interstate highways, with significant north south routes of I-95 and I-81 and east west routes I-270. These linkages also include major north south and east-west rail routes provided by the Norfolk Southern, the Chessie System and AMTRAK. The I-95/I-64 corridor, stretching from Wilmington to Norfolk, is a key route binding the entire megaregion together.

Figure 13 Major Transportation Infrastructure within the Chesapeake Megaregion
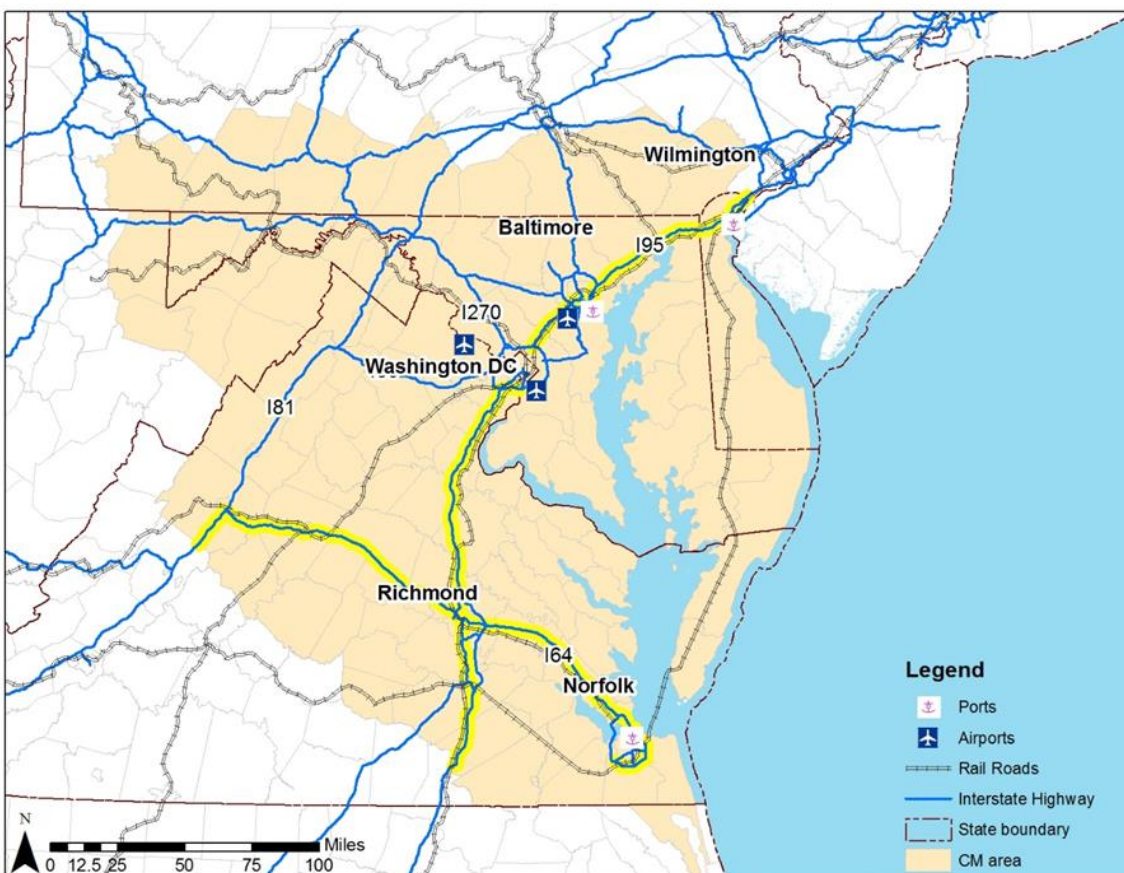
Source: American National Atlas. Railroad, 2004. <http://nationalatlas.gov/mld/railrdl.html> (November, 2012).

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[21] American Association of Port Authority, 2011

Population and Employment

In 2010, the Chesapeake Megaregion has a population of 15 million and employment of 9 million in 2010.[22] Population is organized by 5 million households.

Figure 14 and Figure 15 illustrates the location of population and employment. The largest population and employment centers are located along I-95 and I-64, with the Washington DC area having the most high-income households. Similarly, as Figure 15 shows, most jobs are located along the I-95 and I-64 arc, and in terms of industry, service and government/military employment dominate. GDP for the Chesapeake Megaregion was $880 billion in 2010, or 6 percent of the nation's GDP.[23] The Chesapeake Megaregion is projected to grow faster than other areas of the northeast corridor and by 2030 will contain more than 7 million households and employment will be above 12 million.
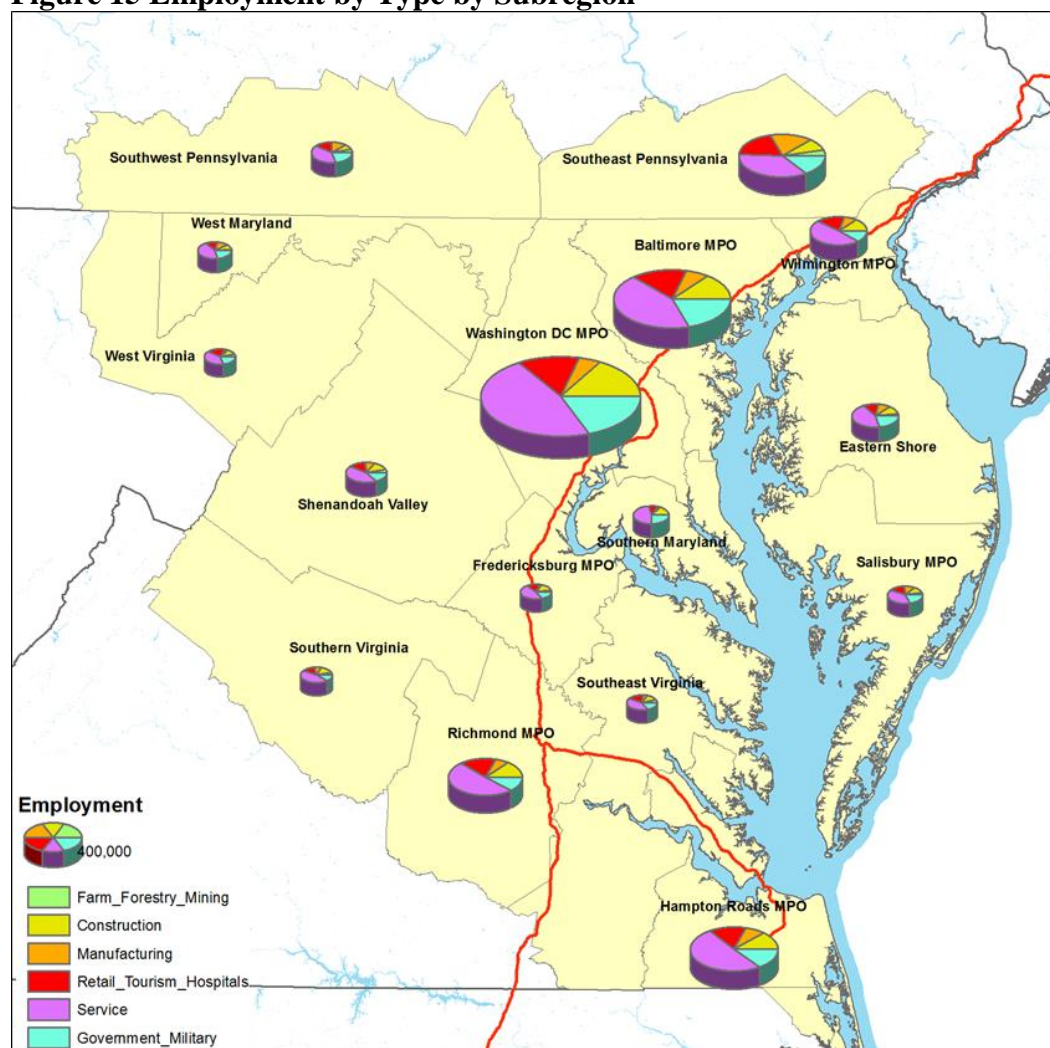
Figure 14 Household by Income Group by Subregion, 2007
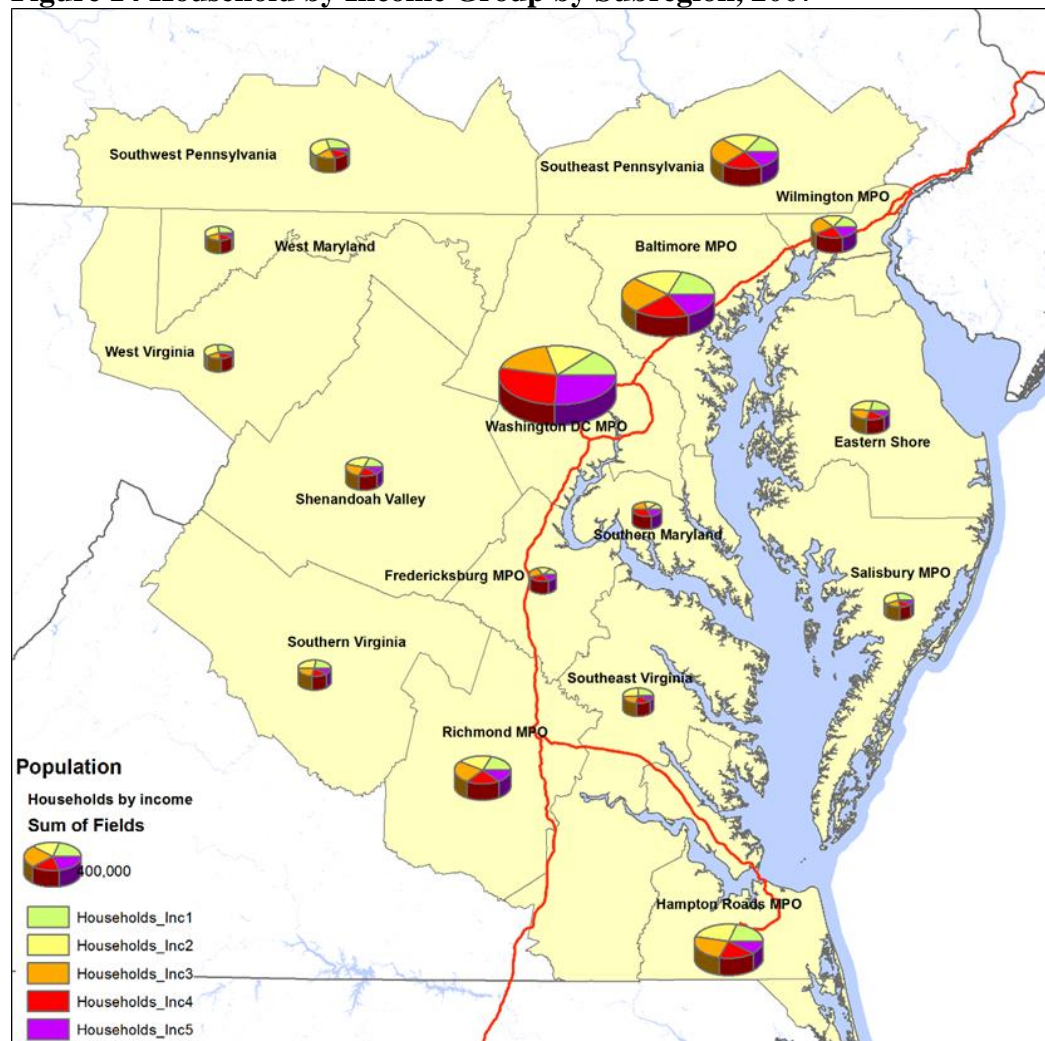
Source: Chesapeake Megaregion Model Outputs: 2007 Base year

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[22] Census 2010
[23] Bureau of Economic Analysis, 2010

Figure 15 Employment by Type by Subregion

Source: Chesapeake Megaregion Model Outputs: 2007 Base year

Industry Mix

The megaregion houses a complex mix of industries including, government, military, health, manufacturing, and recreation. Basic industrial employment constitutes about one -third of the Chesapeake Megaregion's employment, dropping to less than 20 percent in 2030. The USDA ERS uses an economic dependence metric, to show where a county's economy is very reliant on key sectors.[24] Approximating this metric in our Chesapeake Megaregion, finds that overall the Chesapeake Megaregion is economically dependent upon government employment (16 percent of the Chesapeake Megaregion employment in 2007, 19 percent in 2030). With the forecast shift from industrial to service jobs by 2030, the government dependency is more pronounced. The Manufacturing share of Chesapeake Megaregion employment (a portion of industrial) is only 5 percent, but the two Pennsylvania subregions are more dependent, having over 15 percent share in 2007. In 2030, there is dependency on government employment for Baltimore, Washington

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[24] US Department of Agriculture, Economic Research Service, Atlas of Rural and Small-Town America, http://www.ers.usda.gov/data/ruralatlas/about.htm

DC, Fredericksburg MPOs, Hagerstown, and Salisbury MPOs, as well as Eastern Shore, Southern Maryland, SE Virginia, and Shenandoah.

The mix of industries is further shown geographically in Figure 16. This illustrates the composition and inter-dependencies in the megaregion. There is a dominant MPO core running north - south along the I-95 corridor from Wilmington, DE to Hampton Roads, VA, which houses the urban services of hospitals, military bases, and manufacturing. The manufacturing spills east and west into areas with natural resources (farming, forestry, mining), and recreation services.

Figure 16 Industry Distribution

Source: MIG, Inc.. IMPLAN System (2009 county-pair commodity data). <www.implan.com>.

Area Types

Area type is defined by activity density; activity here refers to the sum of household and employment. Land is assigned to one of four types (rural, suburban, urban CBD) based on its activity density (number per acre land) at a transportation analysis zone level.
Figure 17 shows area type in 2007. The darkest two shades indicate areas of CBD and urbanized areas of high-density (an activity density[25] of over 12.0) mix of households and employment (Area Type as calculated in the Chesapeake Megaregion model). The surrounding pink zones are less dense suburbs, in a sea of gold areas of rural density (below an activity density of 3.5).The figure echoes with the household/employment geographic concentration phenomenon that I-95 and I-64 arc is home to the majority of activity within the Chesapeake Megaregion.

Figure 17 Area Types within the Chesapeake Megaregion
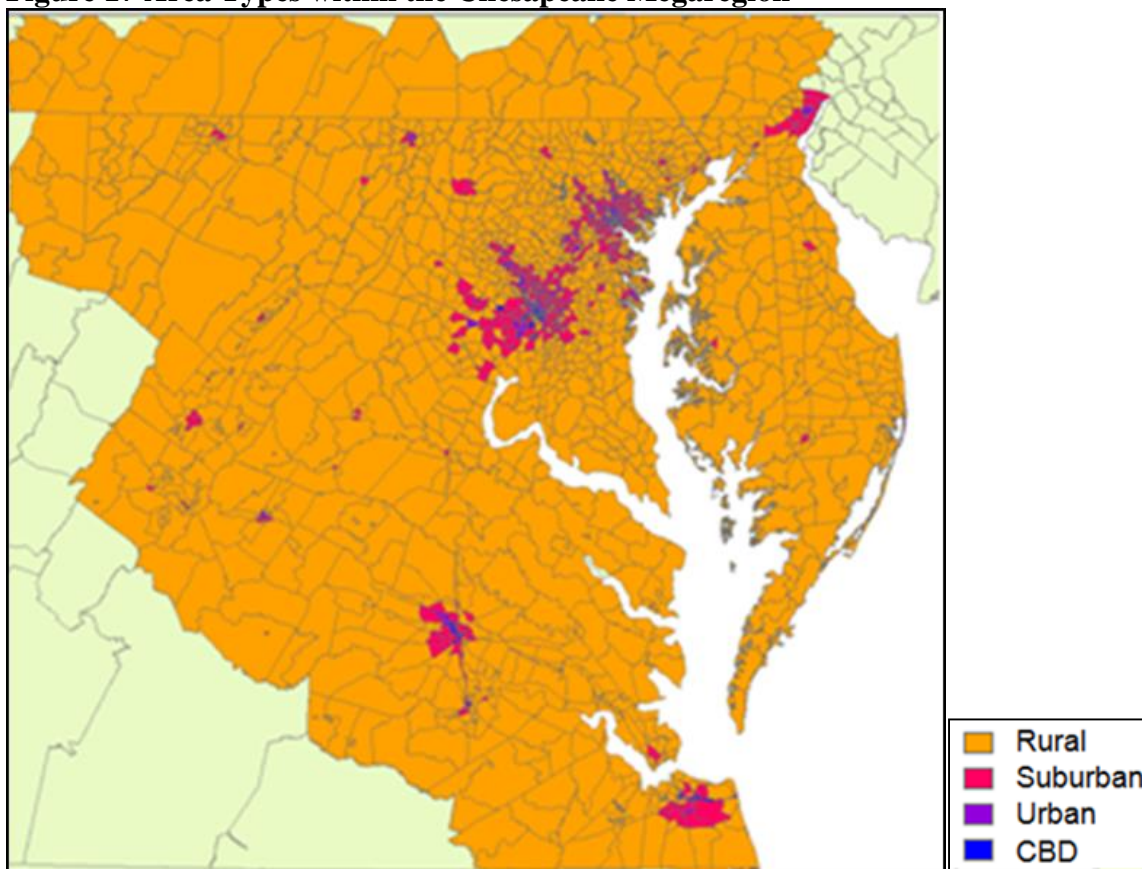

Source: Chesapeake Megaregion model input data

Ports

The Chesapeake megaregion contains three major ports, Wilmington, Baltimore and Norfolk (In discussing Norfolk, Hampton Roads is also included). Figure 18 shows the current tonnage and projected growth in tonnage through each of these ports. Figure 19 illustrates the percentage of landside access by mode to each port.

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[25] See details in Appendix C Data Preparation

Truck access dominates traffic in Baltimore. Staff at the Port of Baltimore indicated during interviews that the Port is a regional port, generally providing shipments to or from locations less than 400 miles from the port. Staff indicated that for trips less than 400 miles the dominant shipping mode was truck, except for shipments of low value bulk cargo. Norfolk on the other hand, serves a much larger area and is a major east coast port. With traffic moving long distance, Norfolk has nearly 50 percent of its cargo shipped by rail. Wilmington is a major destination for oil tankers. These ships typically transfer much of their cargo to smaller ships for movement to refineries or pipelines, thus accounting for the high percent of access by water.

Figure 18 Growth of Ports (Tonnage), 2007-2030
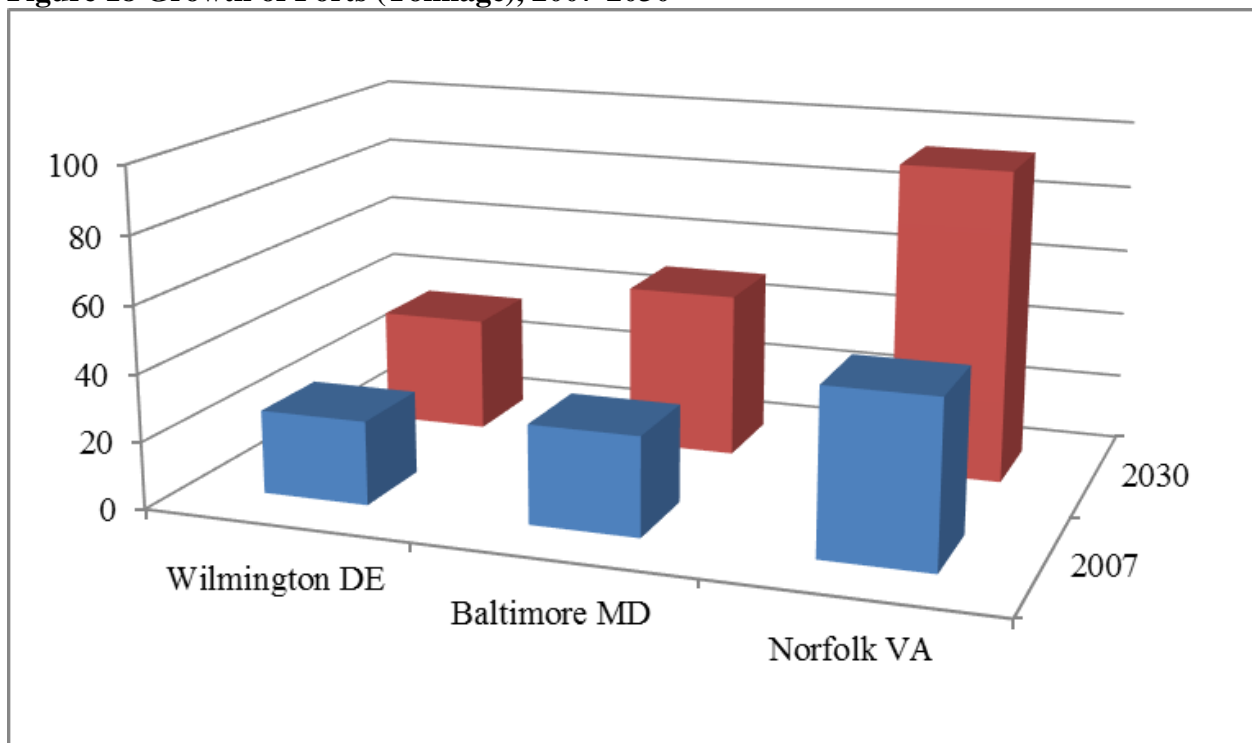
Source: Federal Highway Administration; Freight Analysis Framework 3.2,
<http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/userguide/index.htm>; (7 January 2012).

Figure 19 Access Modes to Ports
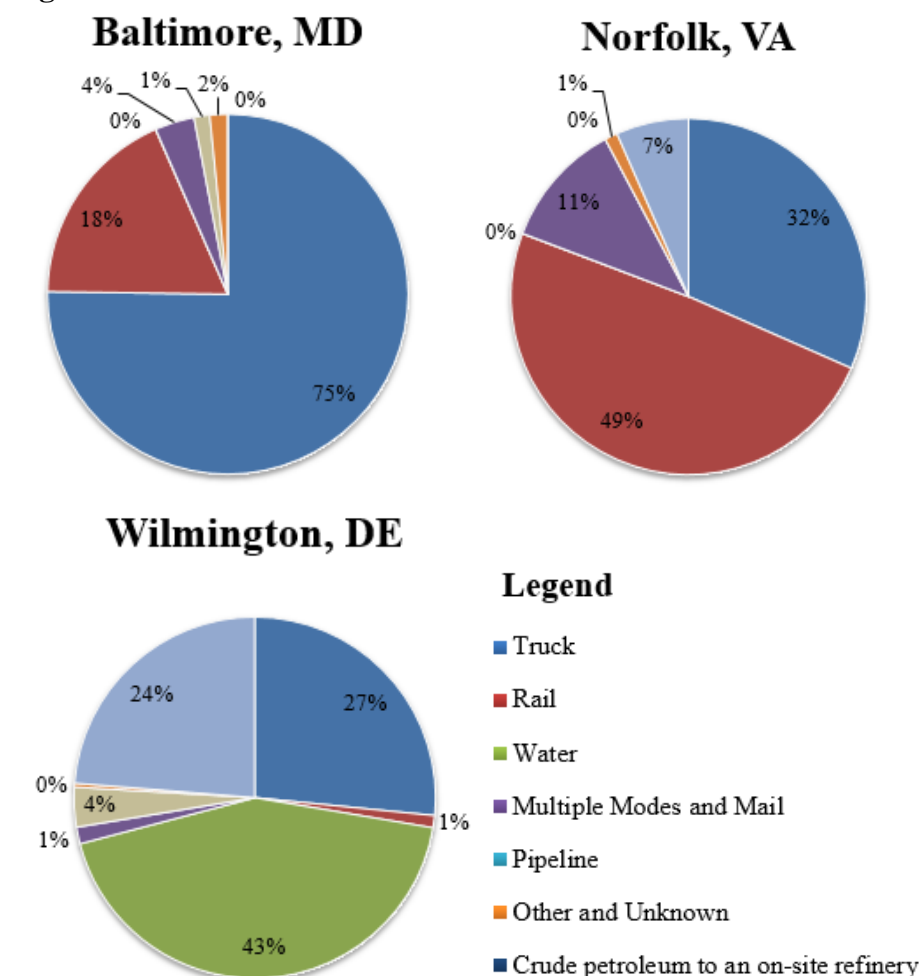
Source: Federal Highway Administration; Freight Analysis Framework 3.2,
<http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/userguide/index.htm>; (7 January 2012).

## 4.3.3. Intermegaregion Demand

Mode Share

Figure 20A summarizes the modal share of goods that are generated in FAF zones that cover the Chesapeake Megaregion study area. The analysis is based on FAF data for the year 2007 using commodity flows in tons. The pie chart size reflects the total volume, and the segments show the modal share. Note that FAF zones and the Chesapeake Megaregion study area do not nest within each other; hence, pie charts at the border of the study area do not represent production in the Chesapeake Megaregion area alone.

With the exception of West Virginia, truck is the dominant mode across all FAF regions in the Chesapeake Megaregion for goods that are produced here. On the average, 76 percent of all goods produced in the area are transported by truck. The 52 percent rail flows in West Virginia are largely due to coal production. Virginia Remainder, Norfolk/Virginia Beach, Pittsburgh and Pennsylvania Remainder are the other zones with a substantial share of rail flows between 23

44

percent and 32 percent. Delaware and Philadelphia send 12 percent and 10 percent of their goods produced by pipeline, which for most part are refinery products. All other non-truck shares are with less than 8 percent relatively small.

Figure 20B shows the same graphic for the other direction, i.e. flows that are consumed in the respective FAF zones. Again, truck is the dominant mode with an average of 77 percent of all goods produced in the area. Richmond receives 33 percent of all goods consumed by rail, and Norfolk/Virginia Beach receives 26 percent by rail. Somewhat surprisingly, West Virginia has with 11 percent the highest share of goods delivered by water, followed by Philadelphia with 9 percent. Elsewhere, flows delivered by water have a share of less than 2 percent. Both for goods produced and good consumed in this area, the share of air is below 0.1 percent. This is common when analyzing flows by weight, as air tends to be used for less heavy but more valuable goods.

**Figure 20 Mode Share of Good Produced in the Chesapeake Megaregion, 2007**
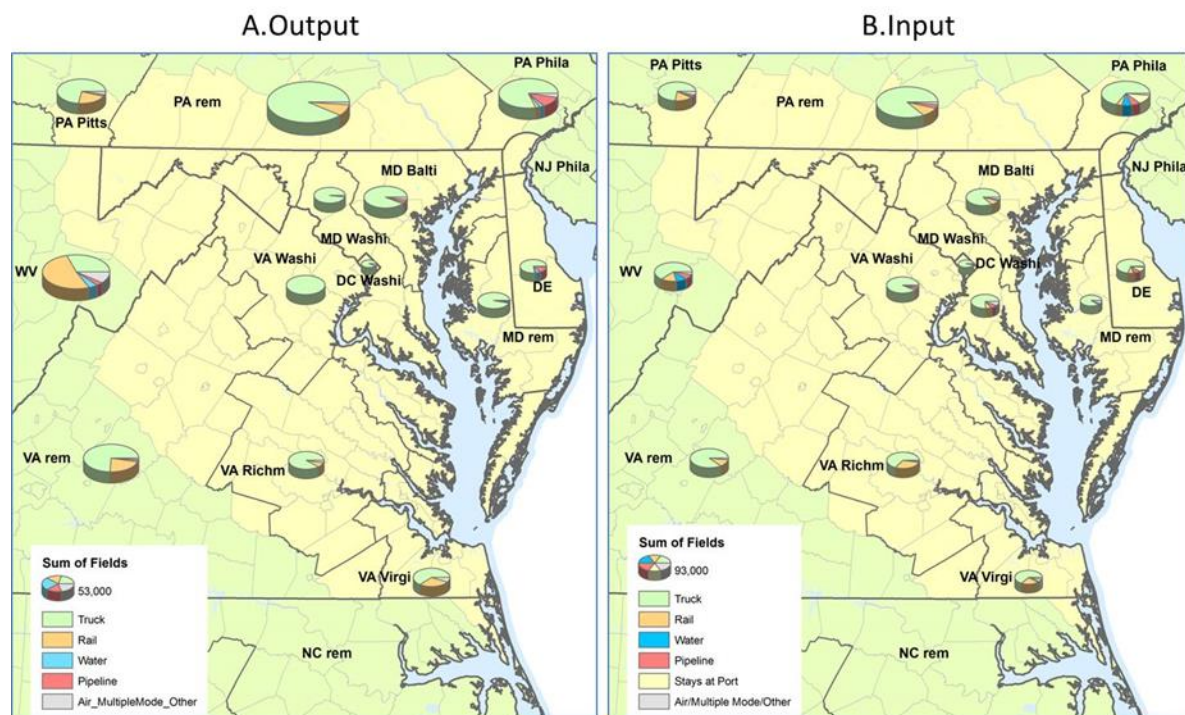
Source: Federal Highway Administration; Freight Analysis Framework 3.2,
<http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/userguide/index.htm>; (7 January 2012).

Commodity Mix

Figure 21 and Figure 22 provides additional information on the six selected employment types, for major areas along the I-95 and I-64 arc within the Chesapeake Megaregion in 2007. As can be seen the Washington and Baltimore areas have large shares of wholesale trade while Wilmington has a large share of Chesapeake Megaregion manufacturing.
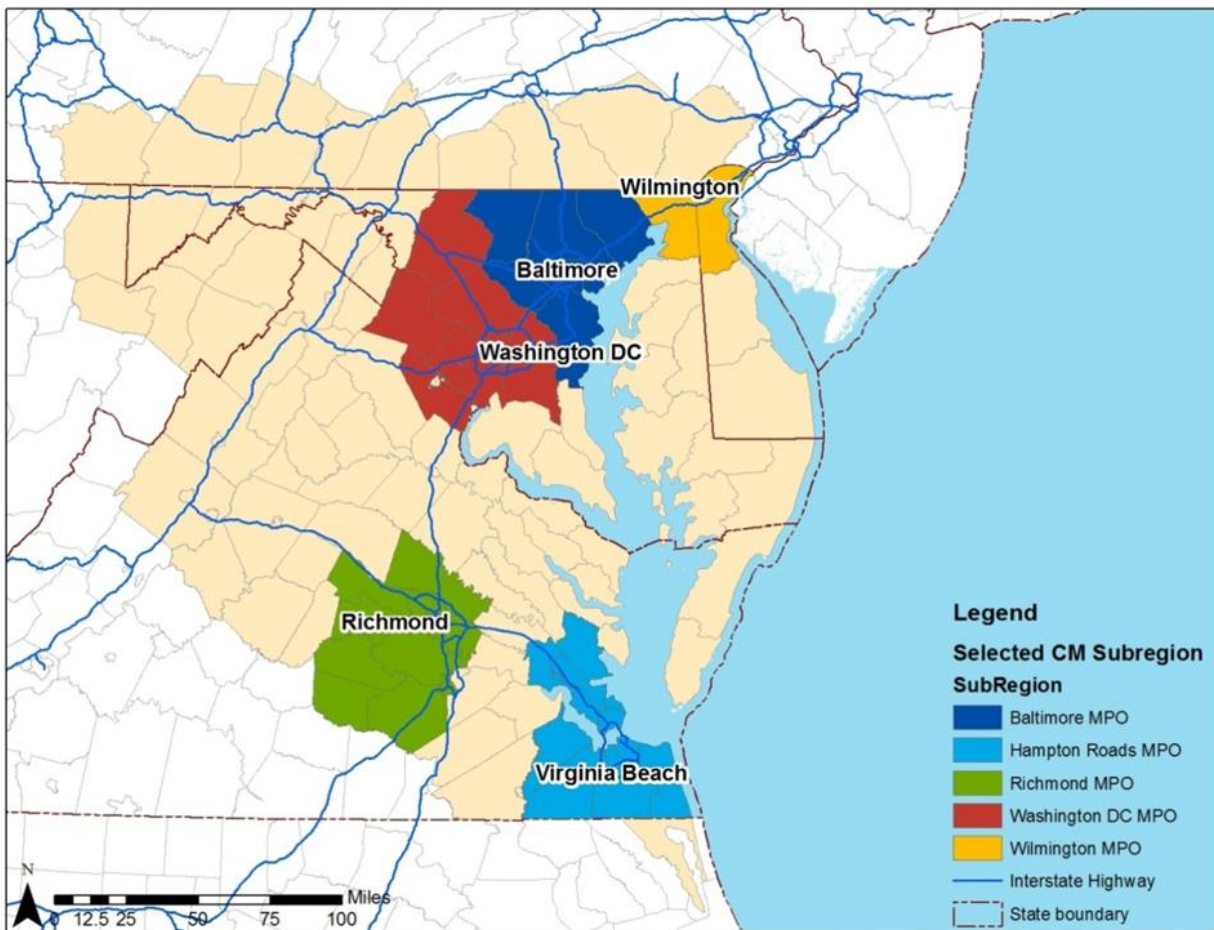
Figure 21 Commodity Flow Production by Truck, Chesapeake Megaregion, by Selected Industry Types (Millions of Dollar, 2009)
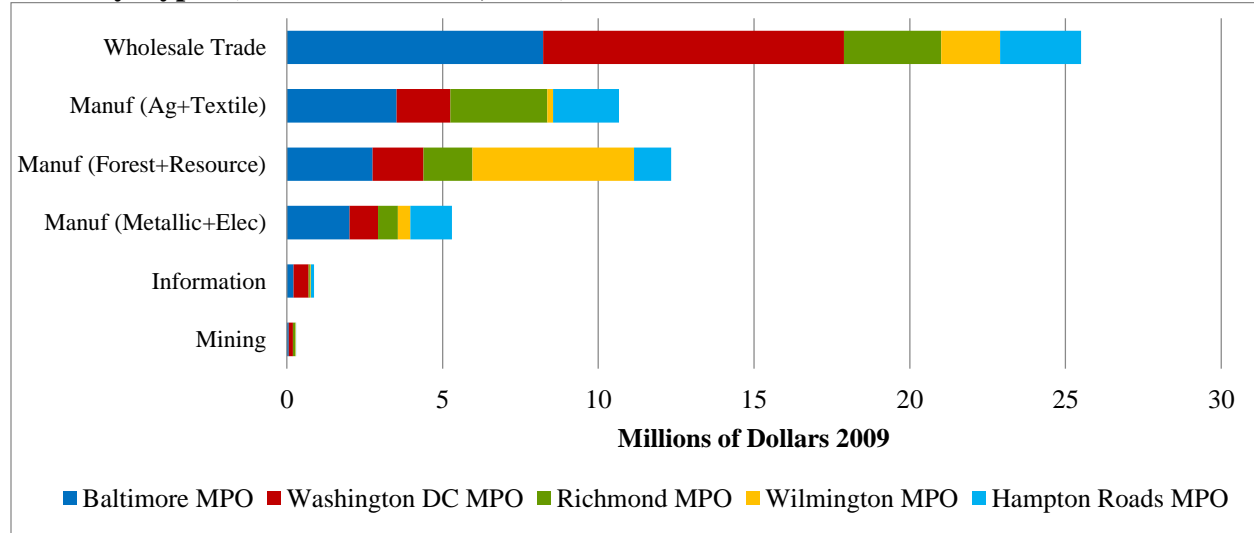
Source: MIG, Inc.. IMPLAN System (2009 county-pair commodity data). <www.implan.com>, EcoNorthwest Haul-Choice Model of truck-dependent industries.

**Figure 22 Location of Selected Subregions for Commodity Flow Analysis**

Production

Figure 23 illustrates what portion of the megaregions share of each activity's production is purchased within the megaregion. For example, nearly 100 percent of management activities within the Chesapeake Megaregion are purchased within the Chesapeake Megaregion. The Chesapeake Megaregion internally produces more than 50 percent of the required products in most industries. The lower share (in red) indicates industries that need to import from area outside the megaregion, which include manufacturing, mining, and agriculture. All of them are resource intensive industries, and material shipping into the megaregion heavily depends on the highway system. These highlight the importance of the transportation function of the megaregion along the eastern seaboard and inland, as well as connecting through seaports to global markets.

**Figure 23 Reliance on Internal Demand**
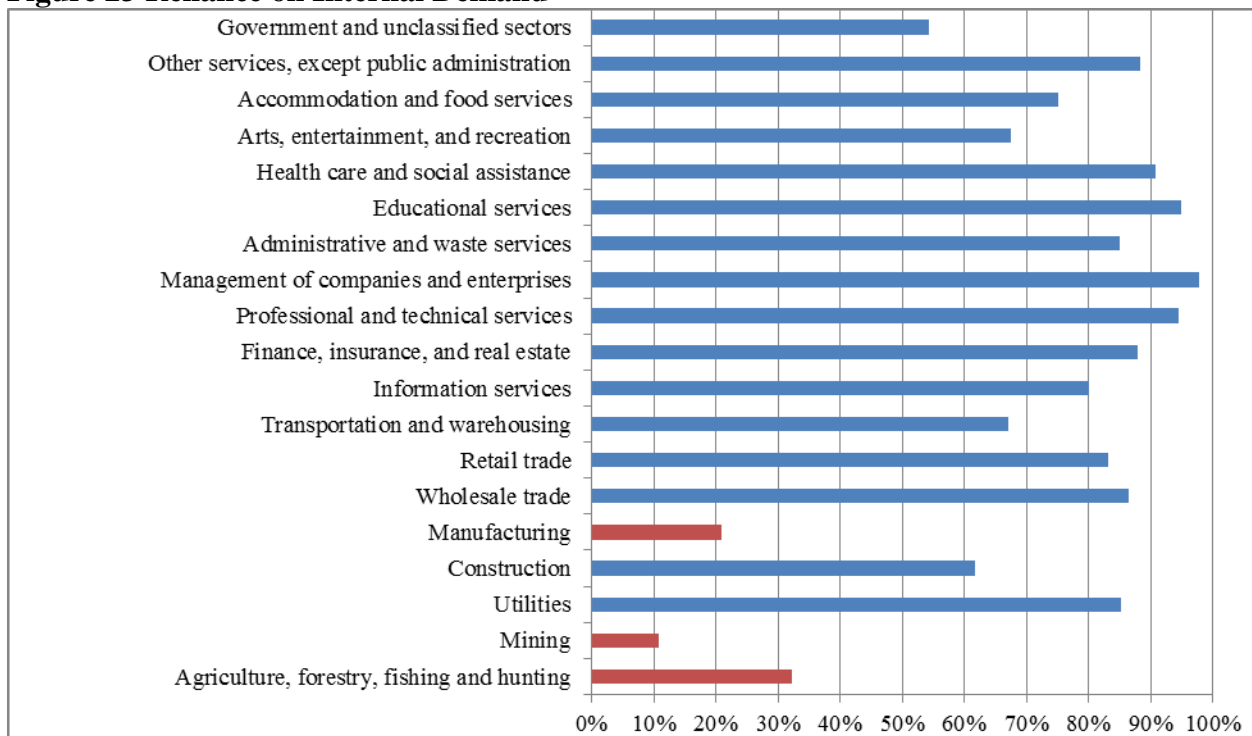
Source: MIG, Inc. IMPLAN System (2009 county-pair commodity data). <www.implan.com>, EcoNorthwest Haul-Model of truck-dependent industries.

Consumption

Figure 24 shows the origin of goods consumed in a given FAF zone covering the Chesapeake Megaregion study area. Again, the size of the pie chart stands for the total amount of goods consumed in a FAF zone. The largest segment shown in green ranges from 52 percent to 64 percent, and shows flows of goods that originate in zones outside of the Chesapeake Megaregion study area. The blue segment shows goods that have been generated in the same FAF zone, and the red segment represents goods that have been generated in any other FAF zone covering the Chesapeake Megaregion study area. Such local flows represented by the sum of blue and red segments range from 36 percent to 48 percent. In other words, every FAF zone within the

Chesapeake Megaregion study area receives at least one third but less than halves of its goods from FAF zones in the Chesapeake Megaregion study area.

Figure 24 Origin of Goods Consumed in the Chesapeake Megaregion
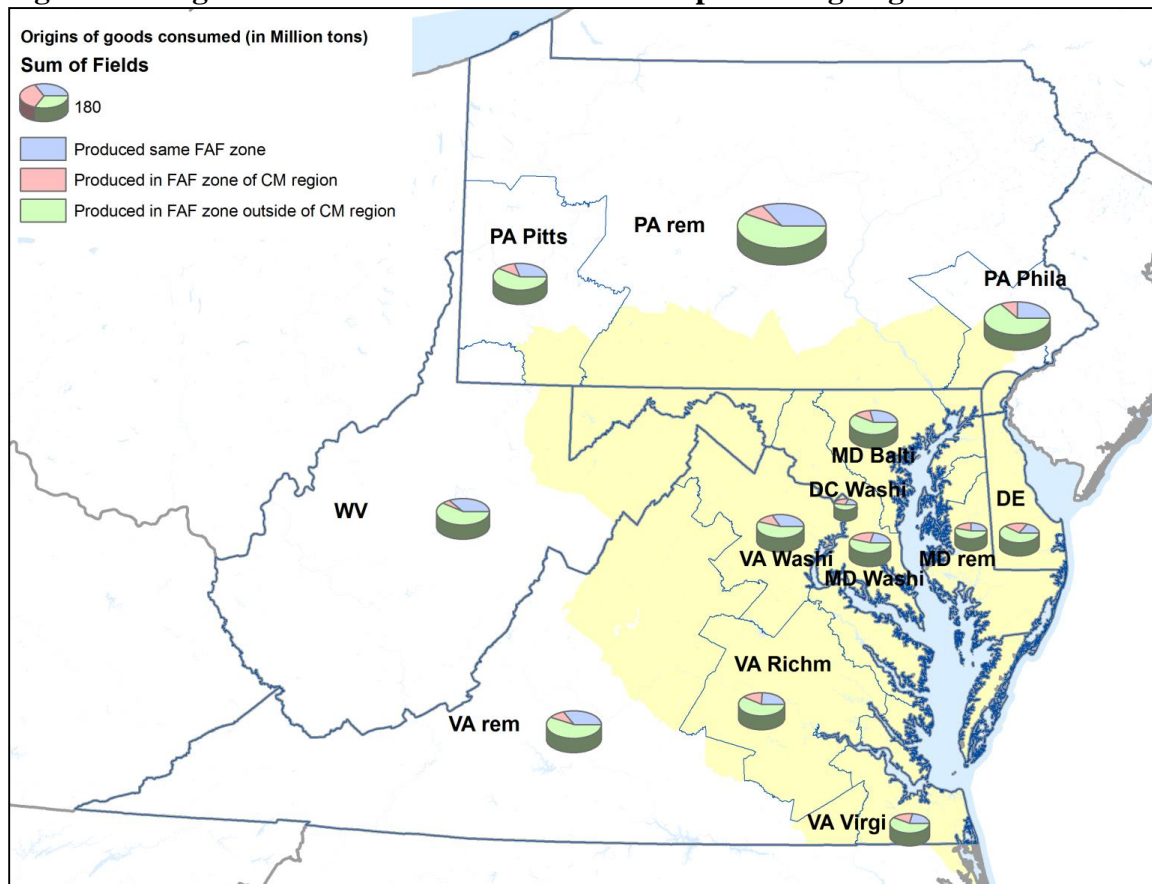
Source: Federal Highway Administration; Freight Analysis Framework 3.2,
<http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/userguide/index.htm>; (7 January 2012).

The internal demand analysis demonstrates the economic connection between the megaregion and external areas, and the reliance on highway system for freight shipping. Though in terms of value, as Figure 23 shows, the "import" share for the majority of industries is not large, in terms of tonnage, as Figure 24 shows, half of the consumer goods are "imported" by highway, demonstrating the importance of the highway network.

4.3.4. Intramegaregion Linkages

Intramegaregion linkages illustrate connections within the Chesapeake Megaregion. The connections presented include commuter flows, freight flows by values and tonnage, and a supply chain analysis in the impact of economic changes by one area on other areas within the megaregion. These flows, when taken together, show linkages within the megaregion and the importance of these linkages on the megaregion economy.

Commuter Flows

Figure 25 illustrates the commuting flows between counties in the Chesapeake Megaregion. This figure shows that there is a nearly continuous cluster of commuting from north of Baltimore down to Fredericksburg also shows clusters around the Richmond and Norfolk areas. This type of pattern illustrates the Ross concept of megaregions containing clusters of metropolitan areas.

Figure 25 Commute Flows by Megaregion Residents
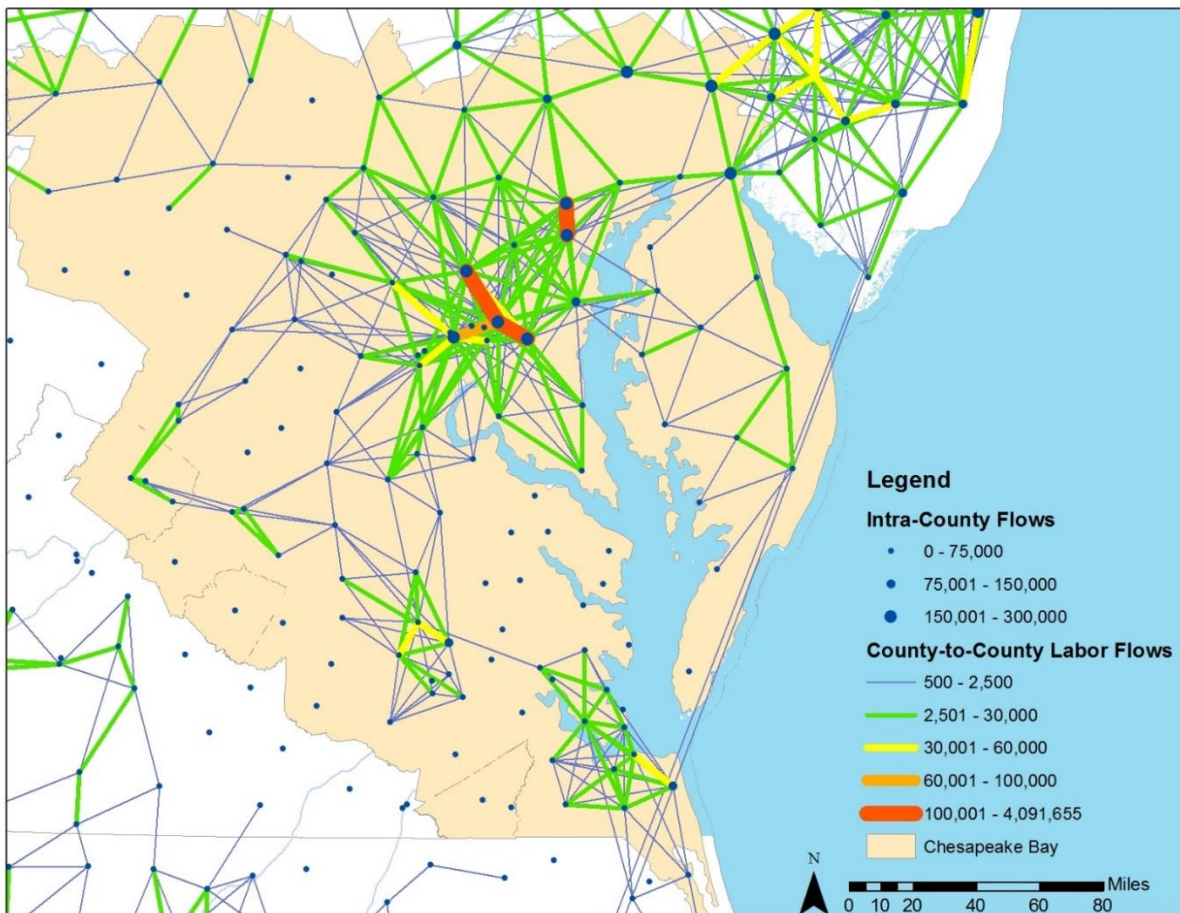
Source: U.S. Census Bureau; American Community Survey, 2006-2008 American Community Survey 3-Year Estimates, Table GCT0101; using American FactFinder; <http://factfinder2.census.gov>; (7 January 2012).

The Economy - Freight Flows

Freight flows among subregions both in terms of tonnage and value help to illustrate freight linkages within the Chesapeake Megaregion. Figure 26 and Figure 27 illustrate the dollar value and tonnage of truck goods movements between the subregions, based on the IMPLAN-dataset.[26] Figure 26 demonstrates the overall strong connection among several subregions in terms of the dollar value of truck goods. Figure 27, on the other hand, illustrates freight tonnage flows between subareas. Both of these figures illustrate that the linkages along I-95 and I-64, from Wilmington to Baltimore, Washington, Richmond and Norfolk are critical to economic

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[26] IMPLAN/EconNW http://implan.com/V4/index.php?option=com_multicategories&view=article&id=632:632&Itemid=10

movements within the megaregion. These routes serve as the backbone of commerce within the Chesapeake Megaregion.

Figure 26 Dollar Value of Freight Flows in the Chesapeake Megaregion
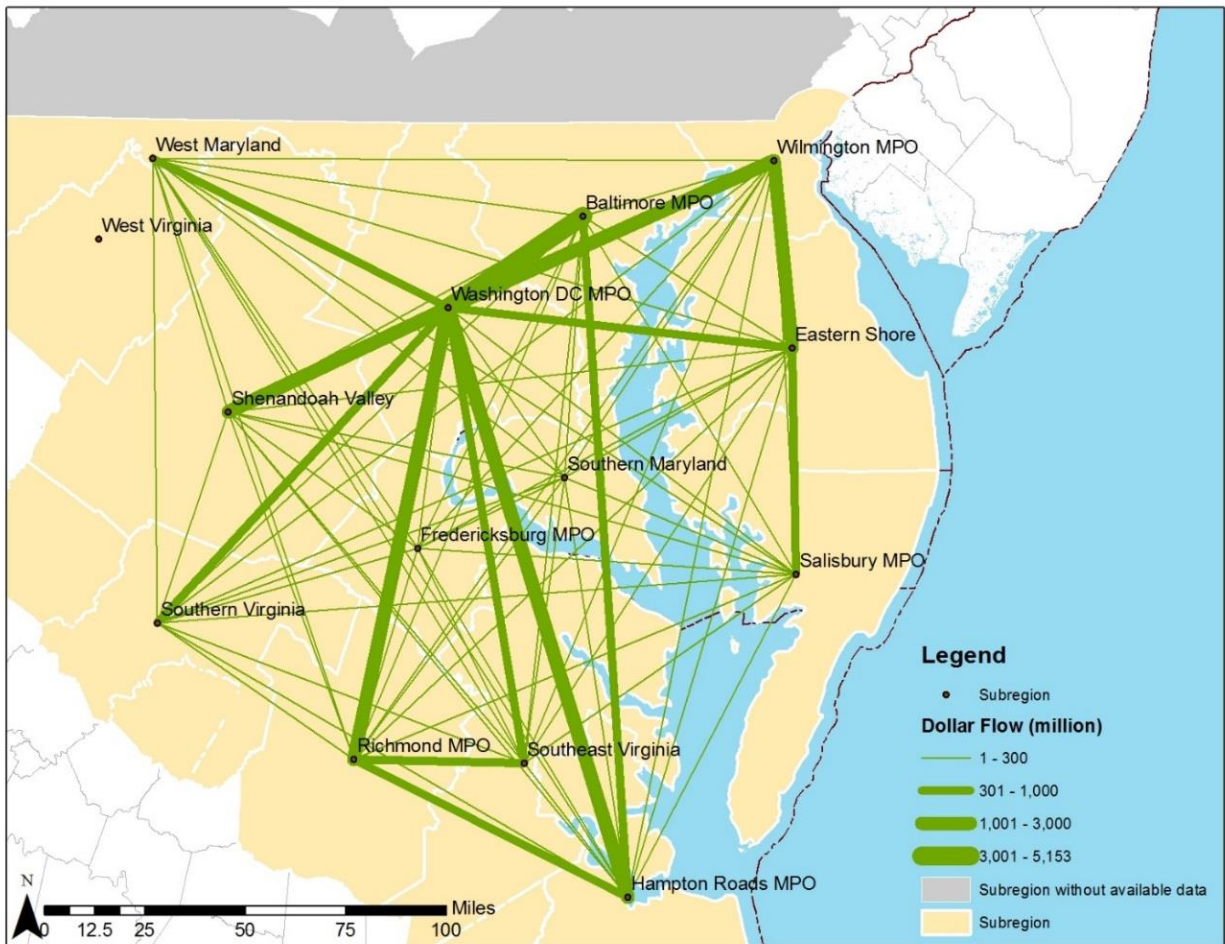
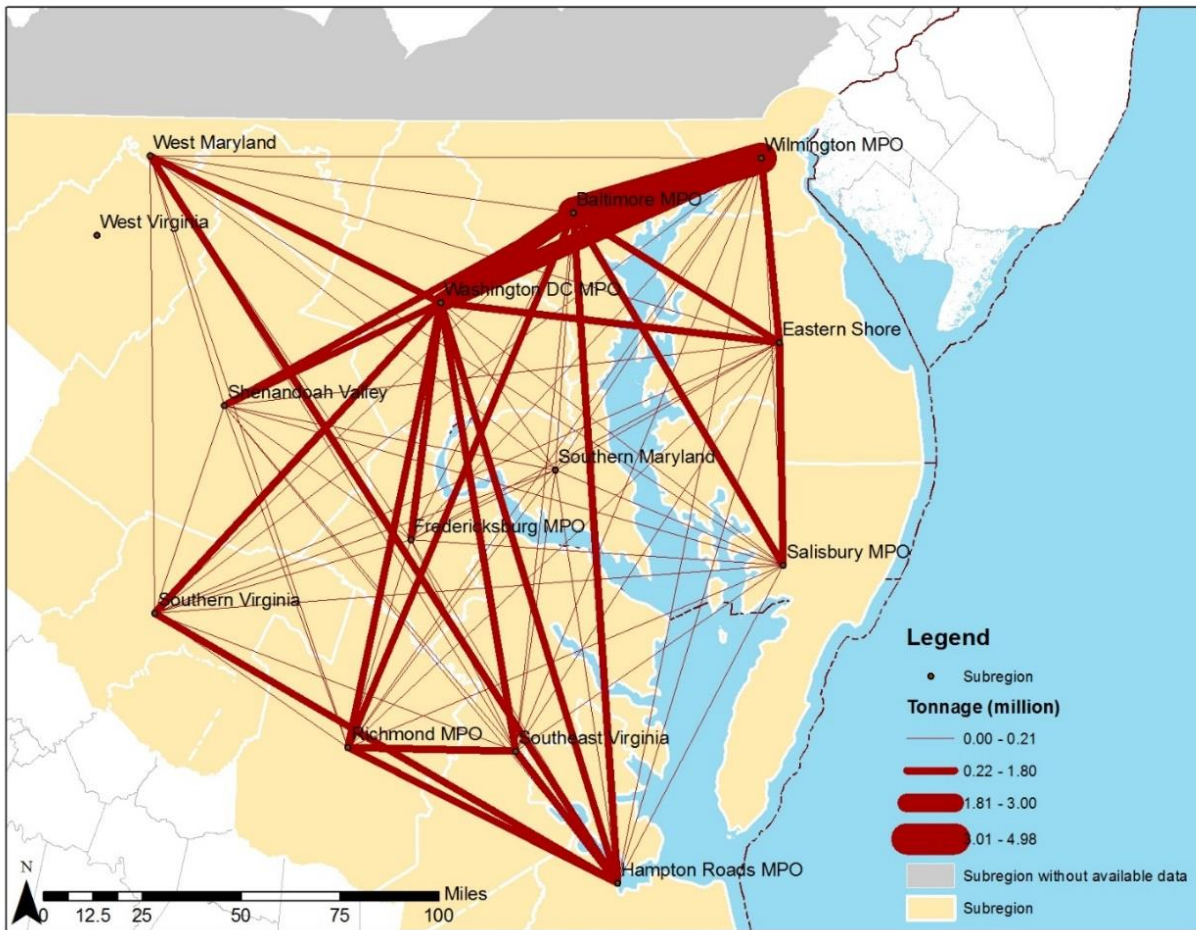Source: MIG, Inc. IMPLAN System (2009 county-pair commodity data). <www.implan.com>, EcoNorthwest Haul-Model of truck-dependent industries.

Figure 27 Freight Flows in Tons in the Chesapeake Megaregion

Source: MIG, Inc.. IMPLAN System (2009 county-pair commodity data). <www.implan.com>, EcoNorthwest Haul-Model of truck-dependent industries.

This section analyzes the freight flows by dollar value and tonnage into and out of Baltimore, Washington and Richmond, identifying the economic linkages with the megaregion.

Dollar Value of Highway Freight Flows from Baltimore, Washington DC and Richmond

Figure 28, Figure 29, and Figure 30, represent the dollar value of freight flows from selected areas within the Chesapeake Megaregion to counties within the Chesapeake Megaregion. These figures clearly show that major core areas, Baltimore, Washington and Richmond, have areas of influence surrounding them, which extend beyond their commuter sheds and MPO definitions. This is particularly true in the case of Richmond, with Richmond's influence extending to the northern border of the Chesapeake Megaregion and down to Hampton Roads-Norfolk. These maps also show that freight considerations cover a larger area than commuting considerations and point to the need to define a megaregion by its freight movements as well as passenger movements. Several area specific conclusions can be drawn from this information:

- Baltimore, Figure 28, generates freight flows to the area which encompasses Washington and extends east into northern Delaware and south to Richmond. This illustrates the Ross concept of influence area, which goes beyond the MPO areas.
- The Washington DC area, Figure 29, generates less freight flow to other counties than either Baltimore or Richmond. This is to be expected since Washington is heavily dependent on government employment.
- Finally, as shown in Figure 30 movements from Richmond tie the entire Chesapeake Megaregion. Richmond exports extend to Baltimore and Delaware in the north and Hampton Roads and Norfolk in the southeast. With respect to freight movements, Richmond has an influence area much larger than the area covered by the Richmond MPO.

Figure 28 Dollar Value of Freight Flows from the City of Baltimore
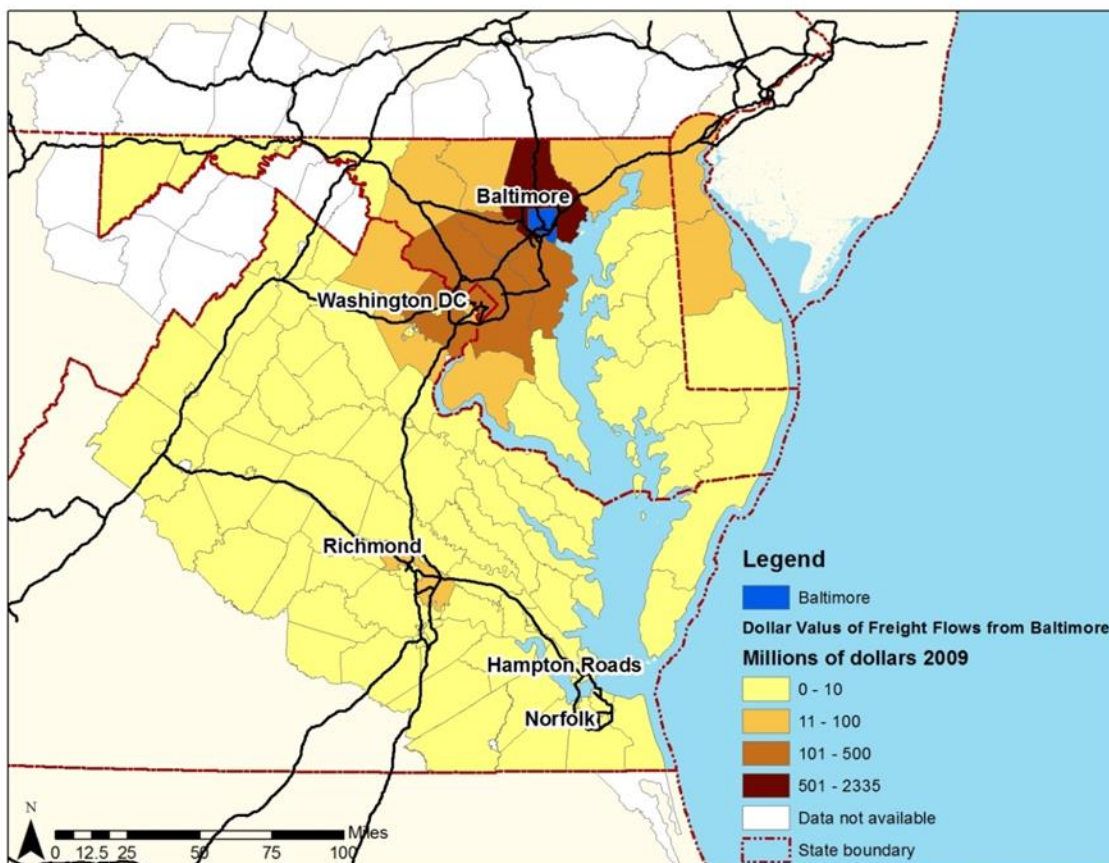
Figure 29 Dollar Value of Freight Flows from Washington, D.C.
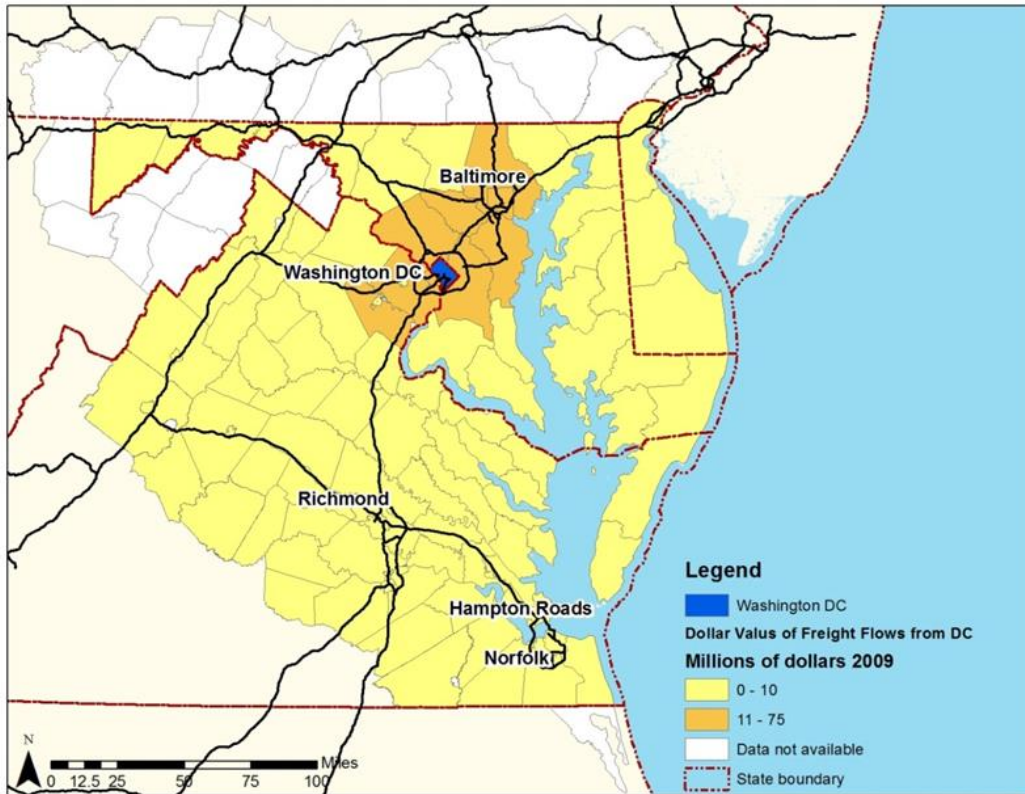
Figure 30 Dollar Value of Freight Flows from Richmond City

Dollar Value of Highway Freight Flows into Baltimore, Washington DC and Richmond

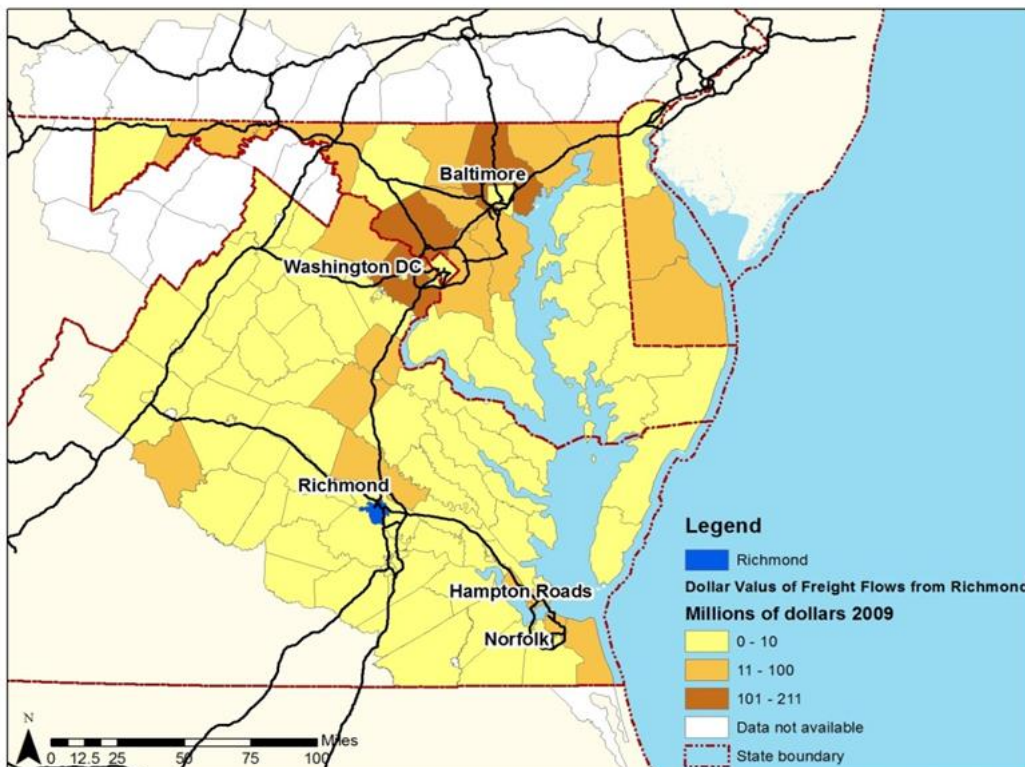Figure 31, Figure 32 and Figure 33 show the dollar value of highway freight flows coming into Baltimore, Washington and Richmond. These figures show that freight moves across the entire Chesapeake Megaregion and that freight links the Chesapeake Megaregion together.

- Baltimore – Imports from across the Chesapeake Megaregion but particularly from Northern Delaware, likely due to shipments into the Port of Wilmington, as shown in Figure 31.
- Washington, DC –Washington, DC, Figure 32, takes in a large amount of freight from across the Chesapeake Megaregion. Comparing this to Washington's exports, Figure 29, it can be seen that Washington imports much more freight, by value, than it exports. His would be expected since as the center of government Washington's primary exports would be finance and services, which do not generate a significant volume of freight.
- Richmond, Figure 33, has low values of imports compared to other areas. However, comparing Richmond's imports to its exports, Figure 30, shows that by values Richmond is a net exporter. When the imports and exports are taken together, it can be seen that there are significant trade flows within the Chesapeake Megaregion and that the economy of the Chesapeake Megaregion ties the Chesapeake Megaregion together.

Figure 31 Dollar Value of Freight Flows into the City of Baltimore

Figure 32 Dollar Value of Freight Flows into Washington, D.C.

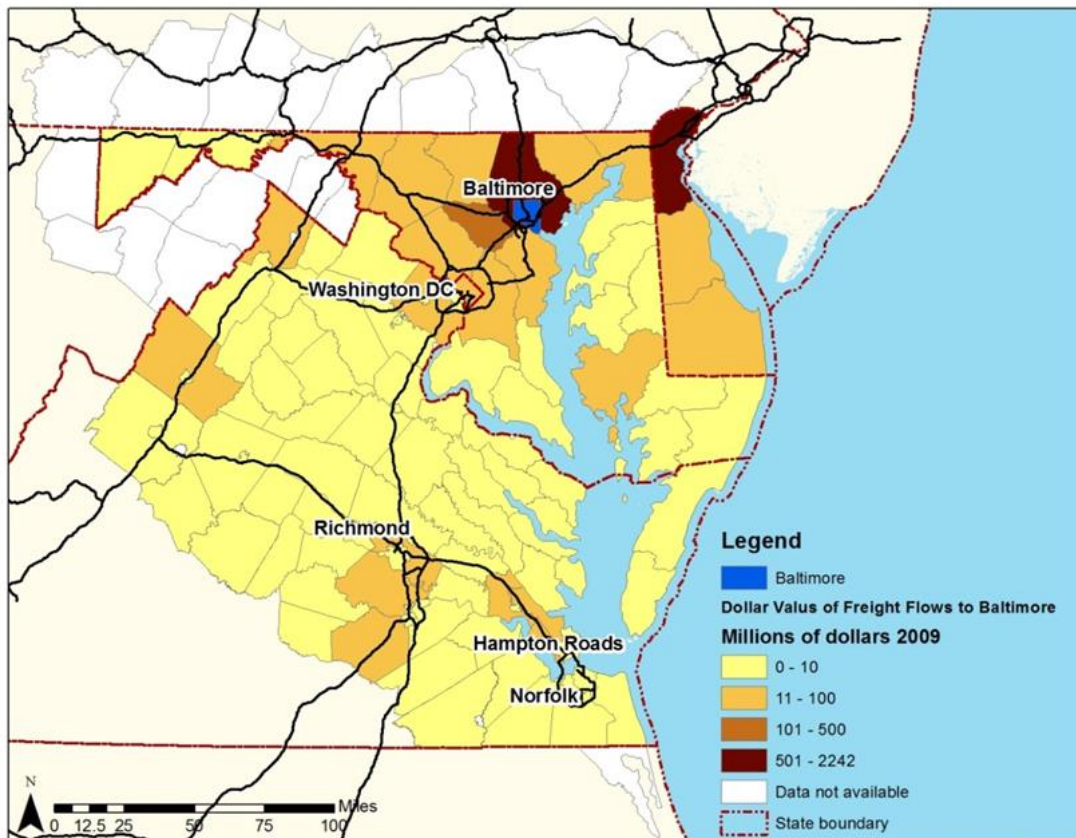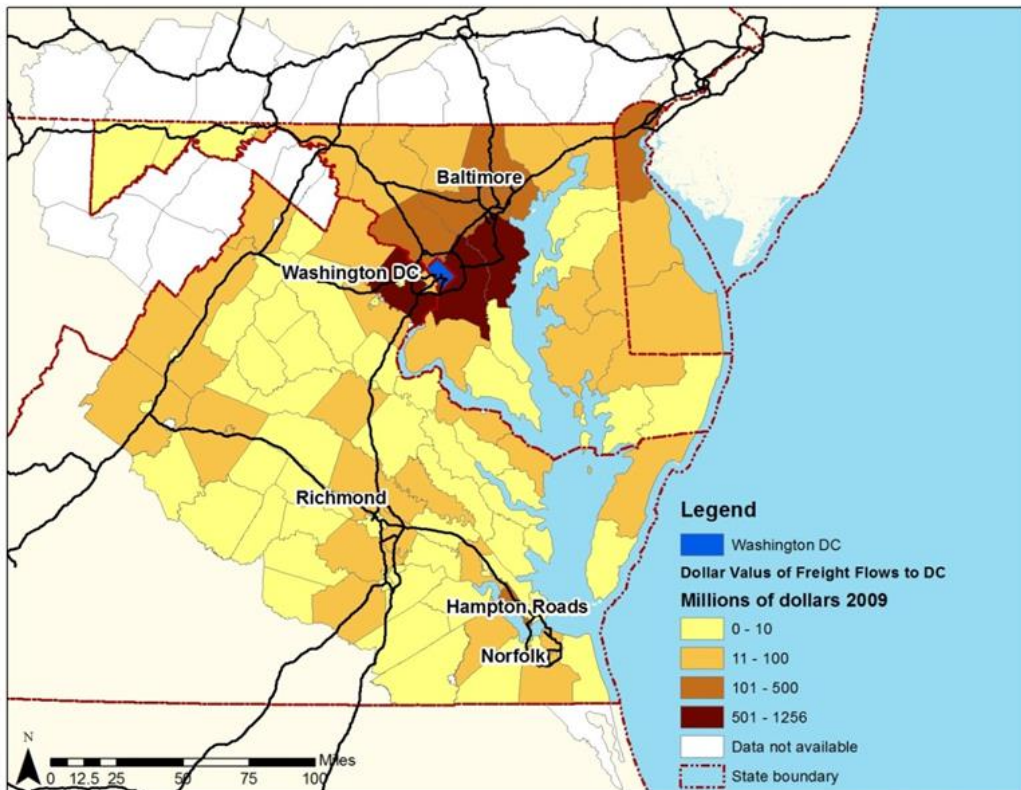

Figure 33 Dollar Value of Freight Flows into Richmond
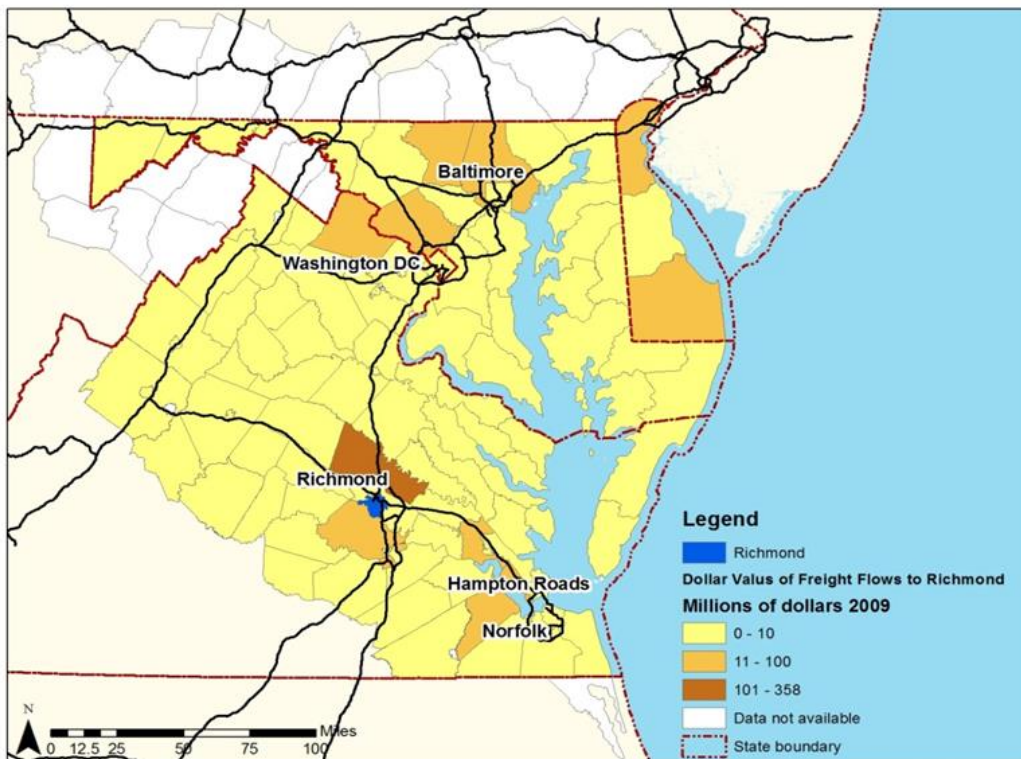
Figure 31 - Figure 33 Source: 2009 IMPLAN&HaulChoice

Supply Chain

To illustrate the Chesapeake Megaregion interconnectivity, the City and County of Baltimore and the City of Richmond were selected and the flow of commodities into, between and out of each of these areas was analyzed.

Counties shipping to Richmond- Richmond to Baltimore - and Baltimore to other Counties

In the first analysis, the trade in tonnage between the City of Richmond, Virginia and Baltimore (city and county) is examined. In this flow pattern, the top eight freight flows into Richmond are mapped. Richmond imports a diverse range of commodities from the surrounding region. In some cases, commodities are shipped from counties near Baltimore, processed in Richmond and shipped up to Baltimore for further processes. This is an example of the specialization in production for individual counties that has been made possible by a reliable transportation network and a highly connected region. Figure 34 shows the extensive range of counties providing incoming commodities to Richmond. The major suppliers are in Virginia and centered near the Hampton Roads port area. To the northwest, another major source of freight flows is from Loudon County, VA.

Figure 34 Freight Tonnage Flows into Richmond, Seven Largest County Flows, All Sectors
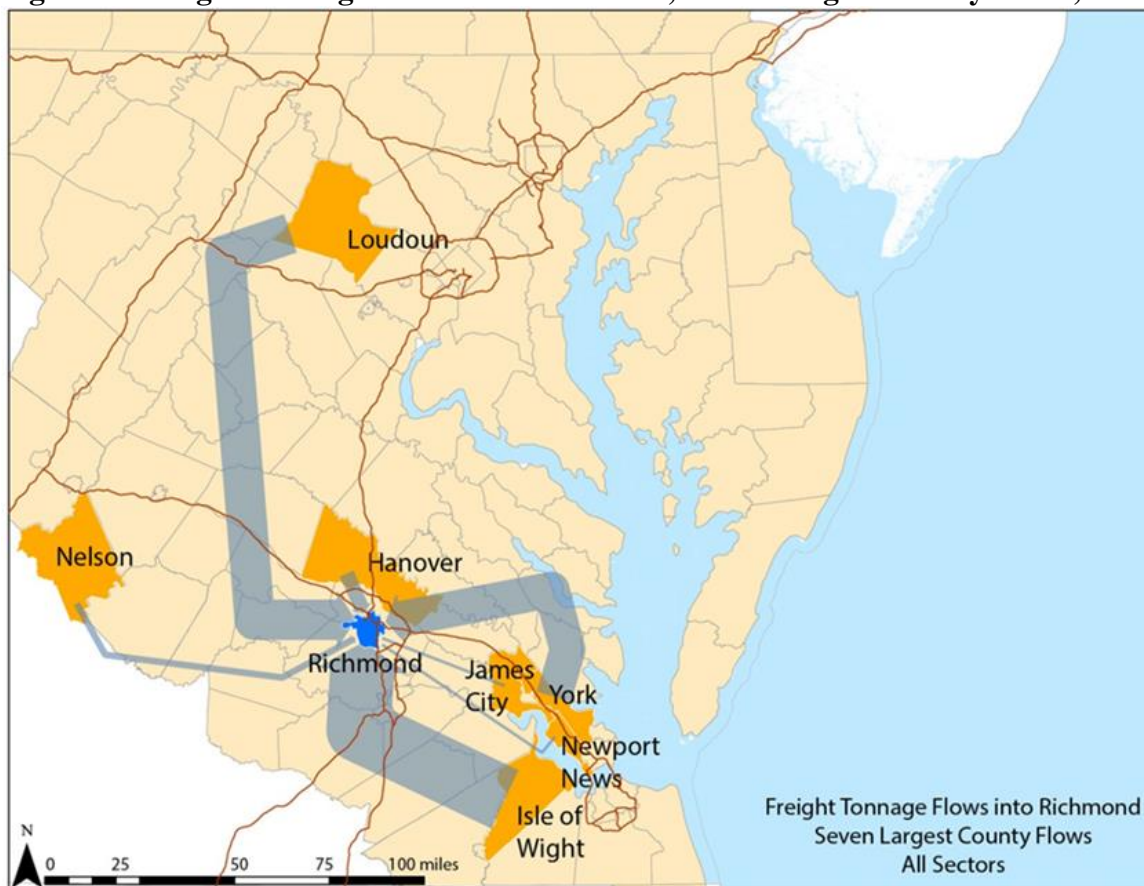
The specialization in production made possible by the interconnectivity of the Chesapeake Megaregion has allowed Richmond to become a major center for paper product recycling and production. This specialization means that Richmond imports from surrounding counties a significant amount of paper related commodities. Trade in this industry makes up nearly 10 percent of all freight entering Richmond from other counties in the mega region. Another important set of commodities for Richmond are concrete and stone-related materials. The shipment of these commodities represents over 16 percent off all incoming freight. These commodities are bulky and expensive to transport. The megaregional trade in for these industries is facilitated by the low transport costs from the underlying highway network.

Figure 35 shows the freight movement from Richmond to Baltimore and the Baltimore exports to other counties directly related to the incoming flows from Richmond. Major commodities moving from Richmond to Baltimore include paper-related commodities, aluminum products, pharmaceutical preparation manufacturing, and seasoning and dressing manufacturing. Outputs related to these commodities are then mapped as shipments to other counties. Major consumers of commodities dependent on trade between Richmond and Baltimore include the surrounding counties of Howard, Montgomery, Prince Georges County Maryland and Fairfax Virginia. These related shipments include stationary products, cardboard and boxes, aluminum alloys, pesticide and fertilizer, and medicinal and botanical manufactured goods. Importantly, this map shows the commodity flow that is dependent on trade between Richmond and Baltimore and subsequently dependent on I-95, the major interstate connection between the two areas.

Figure 35 Richmond to Baltimore Supply Chain, Seven Largest County Flows, Selected Sectors
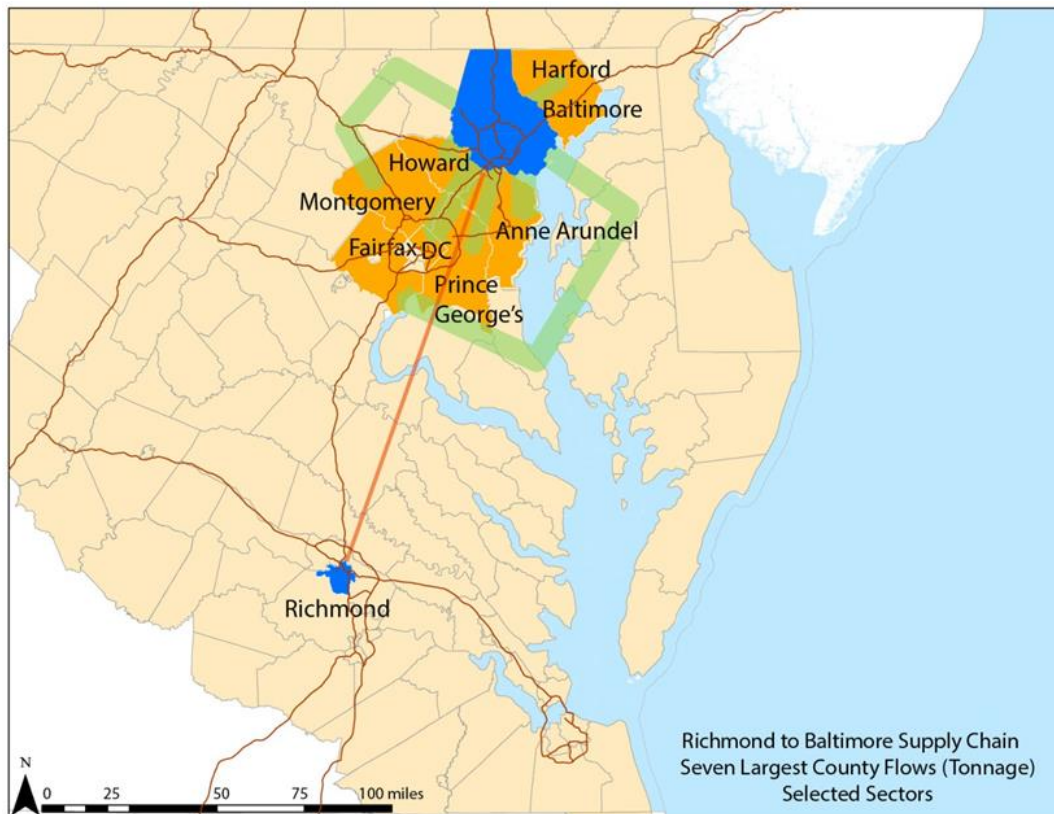
Table 2 provides a list of the major commodity flows from Richmond to Baltimore, their rank in terms of total trade between the two cities and the percent of total trade between the two locations (in tons) that the commodity makes up. The table shows that paper related commodities make up the bulk of shipments from Richmond to Baltimore. As mentioned previously, Richmond specializes in the paper industry and is a major supplier of related commodities, especially to Baltimore where many goods are manufactured using these products.

Table 2 Commodity Flow Share from Richmond to Baltimore

Rank	Percent (of total trade)	Commodity Description
1	37.66 %	Paper mills
2	9.86 %	Aluminum product manufacturing from purchased aluminum
3	7.79 %	Pharmaceutical preparation manufacturing
4	6.71 %	All other paper bag and coated and treated paper manufacturing
5	5.45 %	Paperboard Mills
6	3.01 %	All other food manufacturing
7	3.00 %	All other converted paper product manufacturing
8	2.58 %	Ornamental and architectural metal products manufacturing
9	2.22 %	Seasoning and dressing manufacturing
10	2.03 %	Urethane and other foam product (except polystyrene) manufacturing

Source: MIG, Inc.. IMPLAN System (2009 county-pair commodity data). <www.implan.com>.

Counties Shipping to Baltimore - Baltimore to Richmond - Richmond to Surrounding Counties

The next set of figures shows the freight flows from Baltimore to Richmond. Figure 36 shows the counties shipping to Baltimore. The graphic shows the greater spatial reach of suppliers. Much of the imported commodities come from along the corridor between Baltimore and the major port areas of New Castle County, Delaware. This trade is also heavily reliant on I-95. Other major commodity flows come from Virginia and rely on I-95. Much as the shipments imported to Richmond, (described above) some of the major flows of commodities into Baltimore come from counties closer to Richmond. This represents flows of goods, which Baltimore specializes in reprocessing.

Baltimore imports a large amount of food related products to support extensive industries in spice and other processed food manufacturing. Baltimore also operates as a manufacturing center for plastics, importing petroleum products and other related goods from surrounding counties.

Figure 36 Freight Tonnage Flows into Baltimore, Seven Largest County Flows, All Sectors

Freight Tonnage Flows into Baltimore
Seven Largest County Flows
All Sectors
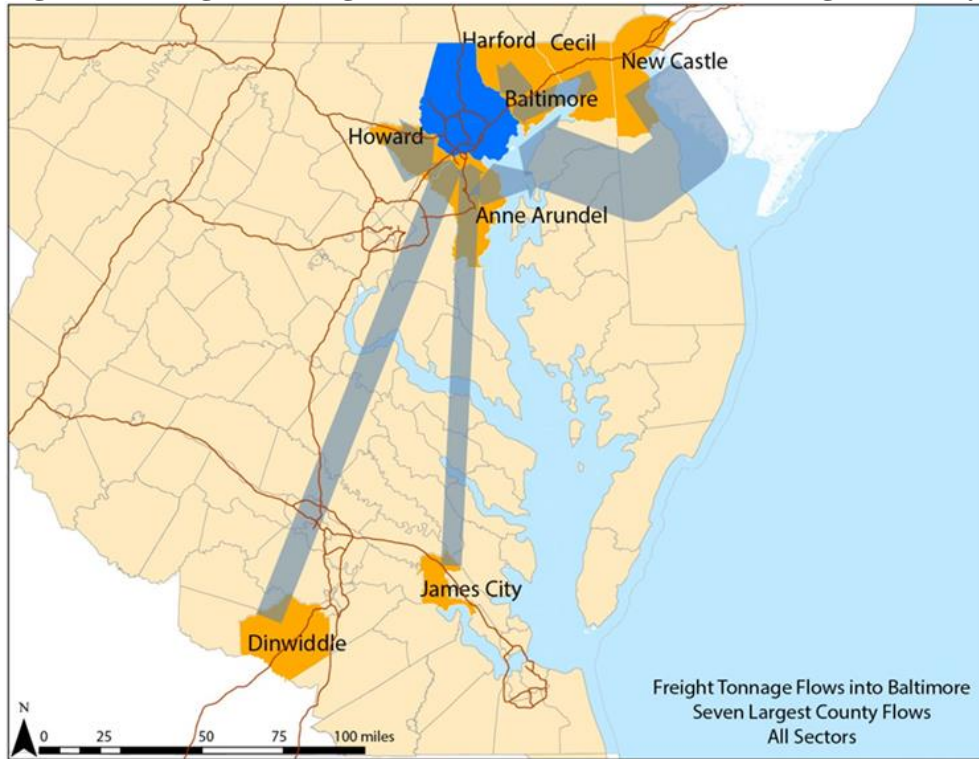
Figure 37 Baltimore to Richmond Supply Chain, Seven Largest County Flows, Selected Sectors
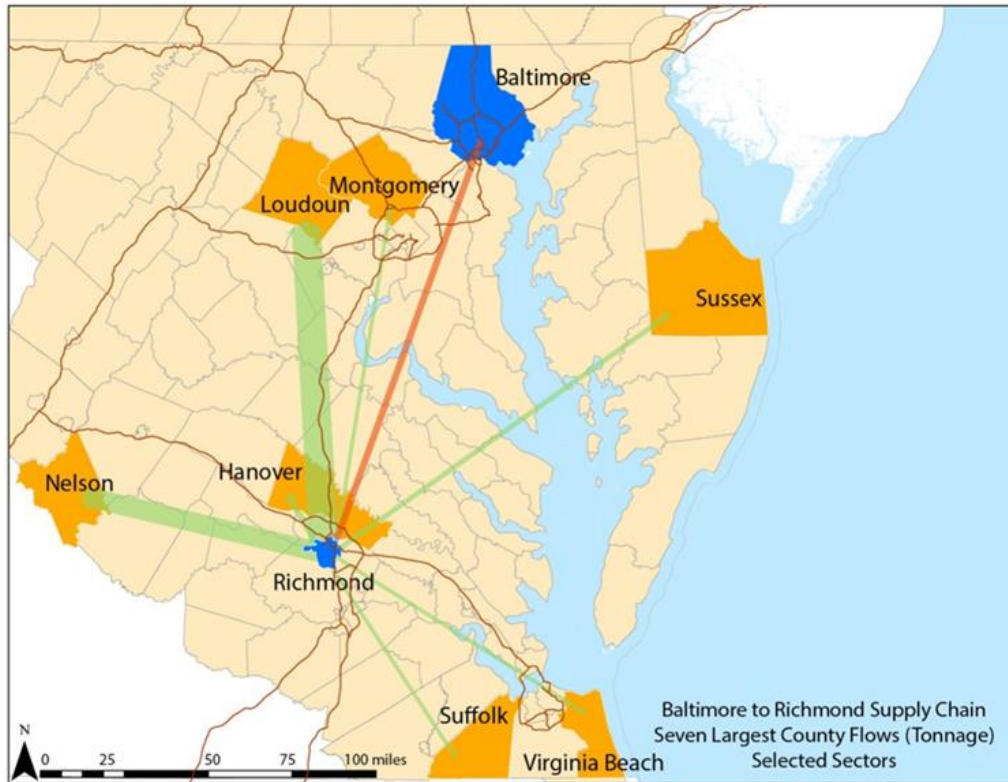
Baltimore to Richmond Supply Chain
Seven Largest County Flows (Tonnage)
Selected Sectors

Source: MIG, Inc.. IMPLAN System (2009 county-pair commodity data). <www.implan.com>.

Table 3 shows the flow from Baltimore to Richmond and the commodities directly related to that trade which flow out of Richmond. The primary commodities shipped from Baltimore to Richmond include iron and steel, output from distilleries, paperboard containers, and many food related products. The figure also shows the expansive consumption of commodities first shipped from Baltimore then exported out of Richmond. These products are directly related to those shipped from Baltimore and include finished food products, smelted alloys, and brewery products. These substantial flows go to nearly every corner of the megaregion; all of which directly depend on movement across the I-95 corridor.

Table 3 provides a list of the major commodity flows from Baltimore to Richmond, their rank in terms of total trade between the two cities and the percent of total trade between the two locations (in tons) that the commodity makes up. The table shows that food related commodities make up the bulk of shipments from Richmond to Baltimore. As mentioned previously, Baltimore specializes in the food industry and is a major supplier of related commodities, especially to Richmond where many goods are consumed or reprocessed for export.

Table 3 Commodity Flow Share from Baltimore to Richmond

Rank	Percent (of total trade)	Commodity Description
1	19.91 %	Soft drink and ice manufacturing
2	19.65 %	Iron and steel mills and ferroalloy manufacturing
3	18.79 %	Distilleries
4	12.51 %	Paperboard container manufacturing
5	9.93 %	Seasoning and dressing manufacturing
6	3.79 %	In-vitro diagnostic substance manufacturing
7	2.02 %	Petroleum lubricating oil and grease manufacturing
8	1.90 %	Cheese manufacturing
9	1.55 %	Bread and bakery product manufacturing
10	1.17 %	Printing

Source: MIG, Inc.. IMPLAN System (2009 county-pair commodity data). <www.implan.com>.

Impact of Economic Changes

Another way to view economic linkage is through analyzing the impact of an economic change in one county on other counties within the megaregion. Impacts on other counties are examined in both magnitude and industry mix. Only the top 10 counties with the largest dollar flows have been shown here (due to the programming limitation).

Figure 38 and Figure 39 illustrate the impact of a 1 percent increase in production in Baltimore on the 10 counties, with the greatest economic interactions with Baltimore. As can be seen the impacts occur as far away as Southern Virginia and Wilmington, Delaware. But the impacts are not uniform. In terms of magnitude, counties surrounding Baltimore, particularly New Castle, Anne Arundel, and Frederick have been impacted the most. In terms of industry mix, some areas, such as Anne Arundel County show the greatest impact on agriculture while others, such as Wilmington, James City and the Isle of Wight in southern Virginia, show the greatest impact on manufacturing.

Figure 38 Impact of 1 Percent Change in Baltimore City and County Production on Selected Counties – Magnitude (in Dollar)
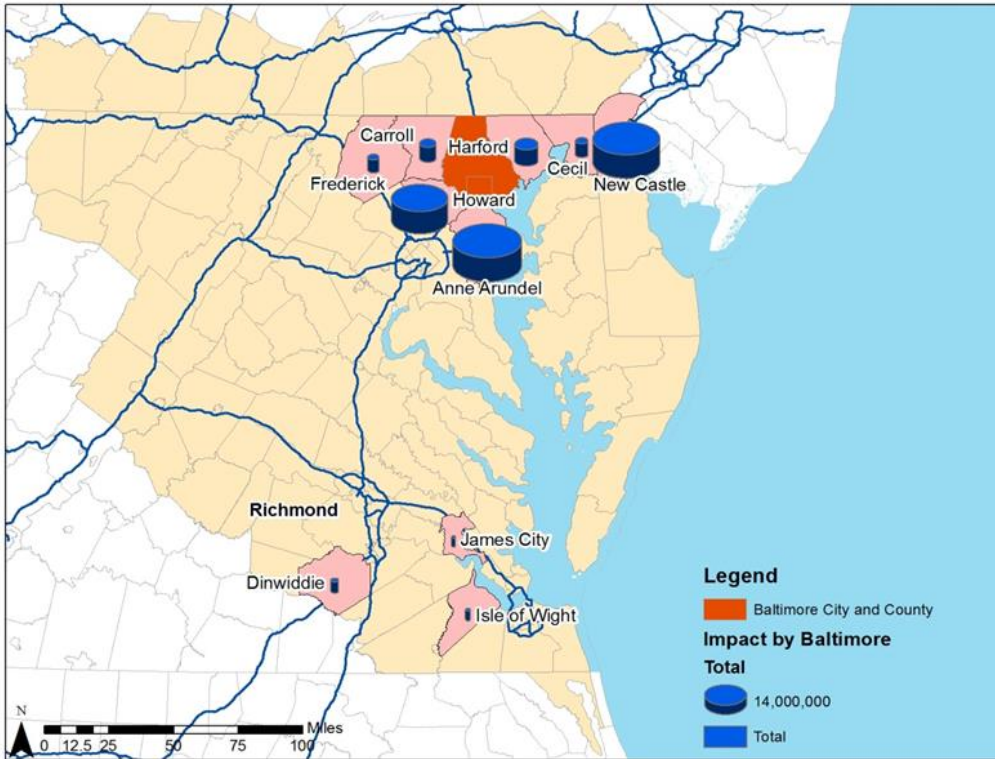
Figure 39 Impact of 1 Percent Change in Baltimore City and County Production on Selected Counties – Industry Share
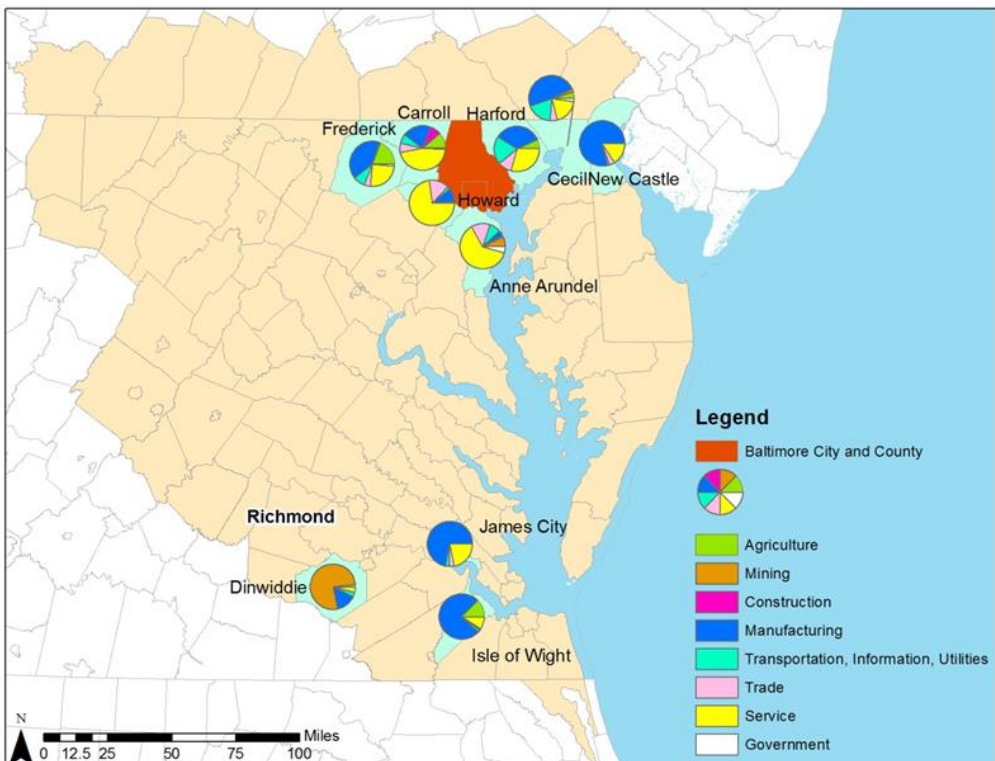
Figure 40 and Figure 41 show the impact of a 1 percent change in Richmond production on the counties with the greatest trade interaction with Richmond. As can be seen, Richmond production has a major impact on across the Chesapeake Megaregion, with significant impacts up to Baltimore and down to areas near Newport News and Norfolk. In addition, the sector impacts are not uniform. In some areas such as Loudon County and James City, the greatest impact is on services while in other areas like Washington County the greatest impact is on manufacturing.

Figure 40 Impact of 1 Percent Change in Richmond Production on Selected Counties – Magnitude (in Dollars)
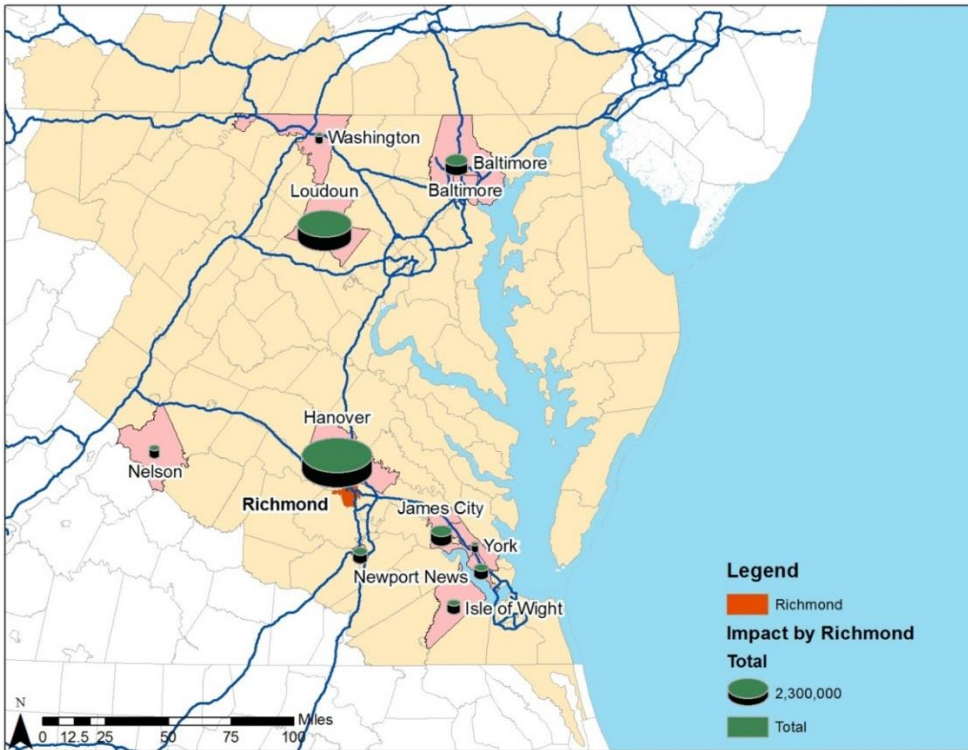
Figure 41 Impact of 1 Percent Change in Richmond Production on Selected Counties
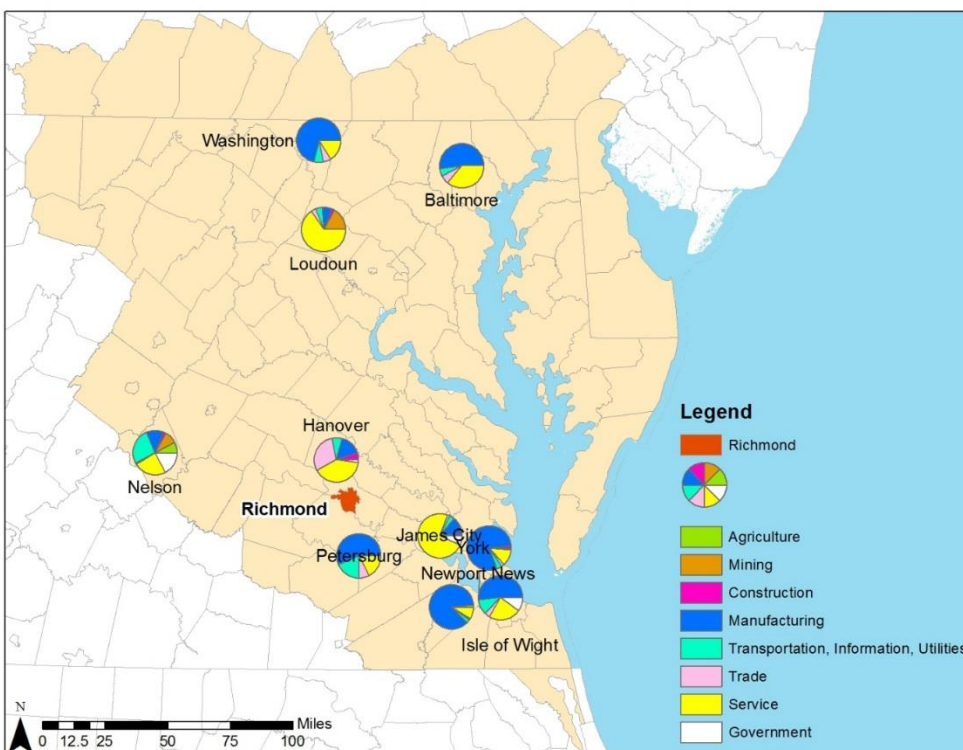
Source: MIG, Inc. IMPLAN System (2009 county-pair commodity data). <www.implan.com>.

Both the Baltimore and Richmond analyses point out the key role played by I-95/I-64 in the economy of the Chesapeake Megaregion. The economic flows identified in these analyses are tied to the ability of the transportation system to move goods along this corridor.

4.3.5. Political Linkages/Local Issues

Political linkages exist today, which can be precedents to Megaregion governance. They extend beyond the state, regional MPO, and county jurisdictions. Examples include the I-95 Corridor Coalition[27] that tackles freight movement and the Chesapeake Bay Commission, which addresses stewardship of the Bay, the unifying economic and environmental heart of the region.[28] Other common issues in the region include congestion and various discussions on congestion pricing solutions, growth in port traffic, land use planning to balance urban and agricultural interests, and environmental concerns about Bay water quality and sea level rise due to global climate change.

4.3.6. Summary

The Chesapeake Megaregion is held together by transportation, economic, environmental and political linkages. Strong economic connections exist among areas within the megaregion, as demonstrated by the value of freight flows in Figure 26. Further, these economic flows are

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[27] http://www.i95coalition.org/i95/Default.aspx
[28] http://www.chesbay.us/

projected to continue in the North-South direction and expand to the east and west in the 2030 Reference scenario. The megaregion contains major highway and rail linkages North and South and also is the terminus of rail and highway linkages to the western part of the United States. All areas share a concern for the health of the Chesapeake Bay, ranging from agriculture to industry to recreation. Finally, political linkages have been formed among the states within the megaregion.

The I-95 corridor coalition addresses transportation linkages and the Chesapeake Bay Commission links Pennsylvania, Maryland and Virginia with the intent of improving water quality in the Bay. For the future, 30% economic growth is forecast for 2030 along with a more dispersed land use pattern. VMT is projected to increase faster than economic growth. Congested speeds will further decline as a result. On the upside with increased CAFÉ, standards Greenhouse gas emissions, along with criteria pollutants, are likely to decline despite the increased VMT.

5. TOOL DEVELOPMENT – CHESAPEAKE MEGAREGION

Tool development depends in part on the policy questions to be addressed. In this section we present the scenario to be addressed, how it would affect the megaregion and then the development of the tools.

5.1.   SCENARIO SELECTION – HIGH ENERGY PRICES

Over the last several years, gasoline prices have been very volatile, ranging from $2.50 per gallon to $4.50 per gallon and higher across the country. Petroleum and energy prices generally are a critical factor in every aspect of transportation and economic activity. They affect the global and local economies, the amount, type and location of employment, residential location and travel behavior. Petroleum prices have a direct impact on the cost of travel by affecting auto-operating cost. The change in auto operating cost also affects residential location and employment location, since these decisions are based in part on the cost of travel, influencing the accessibility to opportunities capitalized into land values. In this section we first discuss the components of auto operating cost, then identify two alternative scenarios, one a reference scenario and the other a sudden rise in energy prices. Finally, we describe the scenarios and how the modeling framework was modified to reflect the scenarios.

5.1.1. Auto Operating Costs

Auto operating cost is a function of the price of fuel, fixed operating expenses (generally assumed to be fixed) and the fuel economy of the vehicle or mile per gallon (MPG). Forecasting either the price of fuel or the MPG with any certainty is a risky endeavor. The uncertainties in each of these are described below. A shift from a gallon to a mileage based taxation system would make such a calculation more straightforward, but is not assumed here.

Price of gasoline. The price of gasoline, as mentioned previously, has been very volatile. National demand, growing international demand, geopolitical instability, natural disasters, ease in accessing available crude oil reserves and refinery capacity all affect the price of gas. While each of these can be forecast to an extent, forecasting them collectively is very risky and uncertain.

Fuel Economy. Like gas prices, forecasting average fleet MPG is also fraught with ambiguity. MPG is a function of many factors:

CAFE standards. The government sets CAFE standards for new automobiles. Vehicle manufacturers must ensure that the new vehicles sold each year, on average, meet the MPG requirements.[29]

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[29] On August 9, 2011, the government announced a fuel economy standard for 2025 of 54.5 miles per gallon (MPG) for cars and light trucks. This analysis in this paper is based on the 2025 standard. Current MPG is 24 mpg, and closer to 30 in Europe.

Fleet turnover. There is a lagged effect in the vehicle fleet adjusting to CAFÉ standards. New cars enter the vehicle fleet at current CAFÉ standards while older vehicles remain in use until disposed of. It can take ten years or more for the bulk of the vehicle fleet to adjust to higher standards.

Price of gasoline. Higher gasoline prices act as a market signal to influence the rate of vehicle turnover to higher MPG vehicles. If high enough, prices could move the average new car MPG above the required CAFE, as evidenced by the absence and high price of low MPG vehicles on used car lots during the 2008 increase in fuel prices.

Engine technology. Engine technology is a wild card. The Argonne (Argonne) labs have reported that with today's internal combustion and diesel technology cars could eventually hit 100 MPG. In addition, plug-in hybrids could raise MPG even more. Development of radically new technologies such as fuel cells with very low cost, without range limits, could significantly change the vehicle fleet, and effectively remove fuels costs as a factor in travel.

The net effect of the above factors is that oil/energy prices will likely rise, the average MPG will likely rise and forecasting future auto operating cost is highly uncertain.

5.1.2. Expected impacts on the Megaregion

High-energy prices can impact all aspects of the economy; total employment, the location of residences and jobs and travel behavior. The type of impact on each of these sectors depends on the magnitude of the price increase, and the timing of the increase. A long slow rise in energy prices would allow location and other factors to adjust to changing conditions. A sudden rise in prices force immediate behavioral responses and not allow for adjustments, which require longer time. In order to narrow the possible scenarios, this section provides a more detailed analysis of the expected effects of an energy price rise and its effects on various aspects of the megaregion.

Economy. A rise in energy prices will affect both the United States and global economies. The severity will depend on the timing and the magnitude. Key factors in assessing the economic impact include, shifts in energy efficiency, relative energy efficiency to competitors, and energy substitution. Sectors that use large amounts of energy or rely on the consumer economy will be pinched by high-energy prices and will be likely to be hit hardest. In summary, high-energy prices are likely to have modest impacts on some sectors of the economy, and thus employment, but not in full proportion to the price increase. Substitution of one form of energy for another, gains in efficiency and changes in behavior can mitigate the impact. This mitigation is particularly true for long run impacts where such long term investments can occur in response to proper price signals. Short run price spikes, like the 1970s, are not likely to have immediate effects on employment but if they remain in place for a reasonable amount of time, employment will be jeopardized.

Freight. Long distance freight shipments are determined by the amount and location of freight consumption and freight production. The INFORUM model forecasts these for each state. Similar to the economic forecasts, due to the mitigating factors the changes to consumption and production under a $5.10 price per gallon of gasoline are less than proportional to the change in

energy cost, due to assumed productivity gains. For example, under the high petroleum price scenario, goods productions in Maryland decreases by only 1.1%, despite a 1% drop in forecast employment (INFORUM).

Land Use. Land use will respond to changes in travel impedance including auto-operating costs (AOC). As impedance increases people tend to locate closer to places of employment and employment, particularly retail, will locate closer to population centers. As impedance decreases land use becomes more dispersed, seeking lower land costs outside the urbanized areas.

Travel. Under a high-energy price future trips are likely to shorten with people changing destinations in order to save on fuels costs, and being more sensitive to distance in their route choice. In addition, fewer trips along with more use of transit, walk, bike, and carpools would be expected. Long distance passenger travel would also respond to fuel price changes, but not to the same extent as local travel. In long distance travel, other travel costs such as overnight lodging and meals reduce the portion of the trip cost related to fuel. However, the purchase of more fuel-efficient vehicles will lower the impact of higher fuel prices on auto operating costs. In addition, as auto-operating costs increase carpooling is also likely to increase. Transit usage may also increase for those who have transit available, and non-motorized is viable for short trips. Under a spike, employment, land use and freight movements will remain fixed in the short term. However, a large impact on travel behavior can be expected.

5.1.3. Scenarios and overall assumptions

Two possible future high-energy price scenarios were identified spanning the possible effects: Reference, in which the price of petroleum rises slightly and MPG remains the same; and a Price Spike in which the price of energy remains relatively constant through 2029, and then jumps to a very high level in a very short period of time.

Reference. Gasoline is assumed to be $2.90 per gallon in 2030 (EIA forecast, without major shocks to the system), with a federal CAFE standard of 54.2 MPG in 2025. The average MPG is assumed to be 41.8, allowing for the fact that the vehicle fleet would not have turned over sufficiently to bring all vehicles to the 54.2 standard. Due to the MPG gains, this represents an auto operating cost (related to gasoline) of less than half of today's (2011). Under this scenario, cars would actually be cheaper to operate than today. This is expected to lead to a more dispersed land use pattern. For the employment and long distance freight forecast, we assume a 2030 Reference economic forecast.

Price Spike. Gas prices rise according to the Reference scenario until 2029 then spike to $14.00 per gallon in 2030, roughly 4-5 times current prices (2011 at $3.50). The United States has experienced fuel price spikes of 100% to 150% in the past. From 1979 to 1980, crude oil prices increased from $15.85 per barrel to $39.50.[30] The price of gasoline doubled from $.63 per gallon in 1978 to $1.25 per gallon in 1980.[31] The causes of these changes were a revolution in Iran accompanied by a significant decline in oil production and the deregulation of the domestic petroleum market. For our scenario, we do not specify the exact cause of the spike. The average

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[30] Wikipedia – 1979 Energy Prices
[31] Flashback - http://www.1970sflashback.com/1978/Economy.asp

MPG, freight shipments and land use patterns would be the same as the Reference due to lack of time and consistent price signals to adjust, with all impacts taken in travel behavior. By using the extreme case of $14.00 per gallon, the scenario clearly points out the trend and order of magnitude of potential impacts and helps to identify possible remedies to such a spike in energy prices.

With the selection of this high-energy scenario three alternatives are available for comparison, the 2007 Base, the 2030 Reference scenario and the energy Price Spike in 2030. Table 4, below, provides a summary of the assumptions used each alternative.

The focus of the scenario analysis will be on identifying vulnerabilities in the megaregion under a high-energy price future. This will point to likely policies and investments that have the potential to increase the megaregion's resilience. As such, it will provide a good foundation to test future scenarios that would exercise possible megaregion policies and investments, and identify their impacts across the various geographic sub-regions and across economic-land use-transport disciplines.

Table 4 CM Case Study Scenario Assumptions

Item	2007 Base	2030 Reference	2030 Price Spike
Gas price	$ 2.12/gal	$ 2.90/gal	$ 14.00/gal
Auto efficiency	24.4 mpg	41.8 mpg	41.8 mpg
Auto-operating costs (AOC)	$0.09/mile	$0.08/mile	$0.42/mile
Economic model	No adjustments	Forecast	
Land use model	2007 SE data (AOC $0.09/mile)	Evolved 2007-2030 (AOC$0.09/mile)	
Short distance Person Trip rates	No adjustments (HH Travel Survey)	No adjustments (HH Travel Survey)	Delphi-panel adjusted
Long distance Person model	No adjustment	Growth-factored based on population	Adjusted to respond to transportation costs
Long distance Trucks model	FAF2007	FAF2030	FAF2030

5.2. SCENARIO ANALYSIS FRAMEWORK

Given the geographic extend of the Chesapeake Megaregion; a single scale model is insufficient to capture relevant activities, travel behavior and their impacts. Instead, a two-layer approach was chosen that distinguishes a megaregional layer represented in more detail and a national layer capturing relevant activities and flows outside of the main study area, including long distance freight and passenger travel. Given the interactions between different megaregions nationally, and in some respect even globally, the two-layer approach facilitates representing the study area in sufficient detail yet acknowledging that megaregions cannot be treated as monolithic islands.

The remainder of this section summarizes the Chesapeake Megaregion analysis framework. It demonstrates the recommended framework discussed in Section 2.4 tailored to local region's context. The basic model functionality is followed by adjustments made to ensure the model was sensitive to the high-energy price scenario used in the case study. More detail about the methodology of the various components, as well as key input data, can be found in Appendices A - D.

5.2.1. Basic Methodology

The model covers the Chesapeake Megaregion area, upgrading the travel demand models adopted from local MPOs, and adding various indicator models. An economic model was built to inform freight movements. A top-down land-use allocation model was developed to link the economic forecasts to the travel model several additional upgrades were made to for this case study to ensure model sensitivity to the impact of significant increases in energy prices on transportation, land use and the megaregional economy.
Figure 42 shows the implemented Chesapeake Megaregion analysis framework. The modules cover the recommended framework elements by including multi-discipline components (economic, land use, transport, environmental and other indicators); multi-modal freight and passenger (long and short) flows; all within a multi-level geographic approach (national, megaregional, and with MPO reconciliation).

Figure 42 Chesapeake Megaregion Analysis Framework
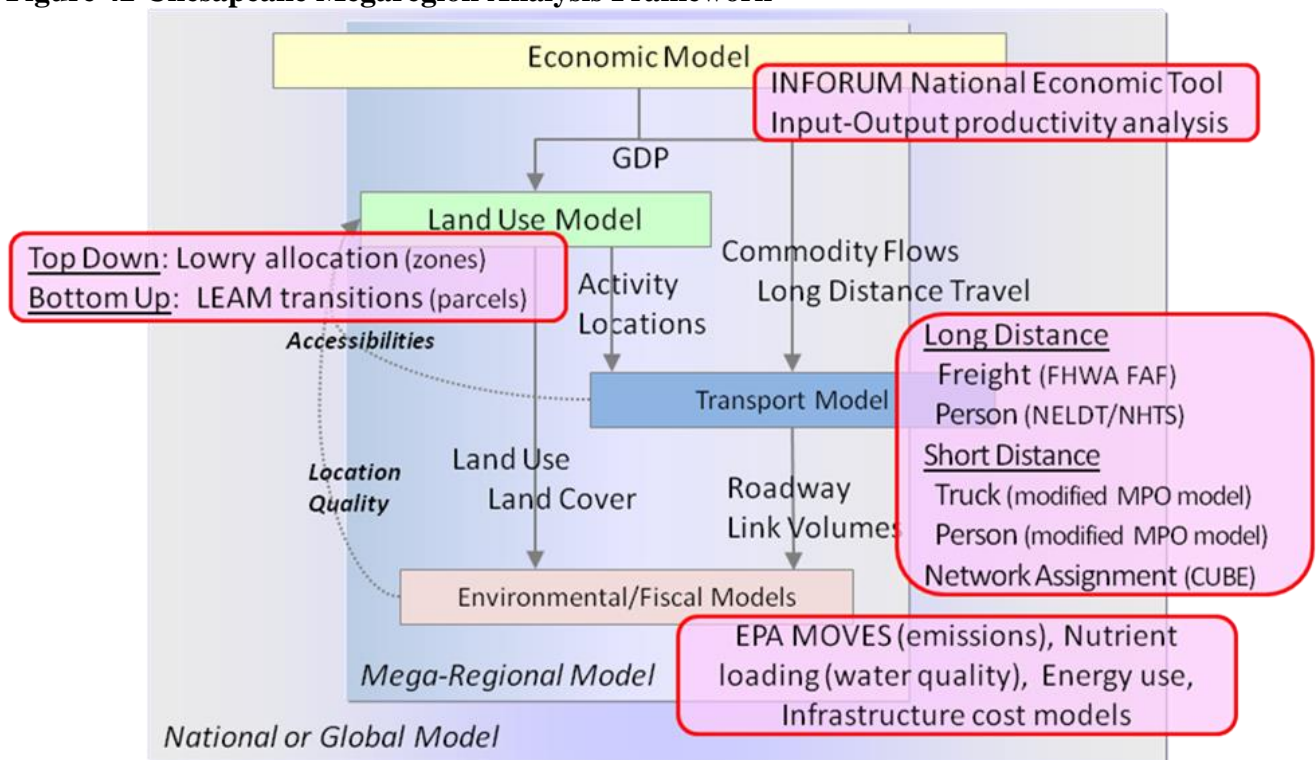
The implemented components can be summarized as follows:

National Economic Model. A proprietary national economic forecasting model built by the INFORUM group at the University of Maryland was applied. It forecasts marginal consumption and production in 65 economic sectors and allocates these forecasts to states. These allocations are also used to adjust the marginal of the FHWA Freight Analysis Framework multi-modal commodity flows.

Land Use Model: Zonal Level Allocation. State level forecasts of basic employment are allocated to counties based on historic patterns of development. Population, followed by retail and service employment is then allocated to counties in 5-year increments. In the horizon year of 2030, a Lowry (gravity-based) top-down land use model then allocates county population and employment totals to model zones.

Land Use Model: Parcel Level Detail. A Cellular Automata model (LEAM model) calculates probabilities of the potential for each cell to change from one land-use category to another, influenced by adjacent cells. Due to limited resources, this model was run only for Maryland. This model was used in combination with a land cover model to estimate nutrient runoff for Montgomery County. This is further described in section 5.3.6 and Appendix D.

Transport Model: Long Distance Freight. The truck portion of the economic model's commodity flow output is disaggregated from FHWA FAF zones to model zones using employment data and inter-industry input-output relationships. Truck trips are assigned to a U.S. network with flows within the megaregion added to traffic projected by other model components and assigned to a more detailed network. Exogenous adjustments to mode shares can be applied; reflecting commodity-distance specific rules and local market knowledge (e.g., rail capacities).

Transport Model: Long Distance Person. The Nationwide Estimate of Long Distance Travel (NELDT) model using NHTS long distance travel data and traveler attributes forms a national model of long distance travel. This travel is assigned to a full U.S. network with flows within the megaregion added to traffic projected by other model components and assigned to a more detailed network.

Transport Model: Short Distance Person. A 4-step travel model from one of the local MPOs was transferred and applied megaregion-wide. Trip purposes, mode choices, and socio-economic data were standardized and applied megaregion-wide. The gravity-type trip distribution model was upgraded to a destination choice model to better address differences in trip lengths and to incorporate megaregional differences in modal options. The mode choice model may be updated to include a tolling option, and to cover both short and long distance modal choices, subject to policy scenarios.

Transport Model: Commercial Vehicles. A local MPO model's commercial vehicle model (simulating both service-oriented non-freight trips and freight-carrying truck trips) was transferred and applied megaregion-wide.

Transport Model: Assignment and Time of Day. A local MPO model's roadway, transit networks and volume-delay functions were borrowed and standardized. Additional US networks were pulled from GIS/travel assignment software packages and local rail/air modal options were

added. CUBE software is used for assignment consistent with the state's MPO models. Time of day factors were developed from Maryland Department of Transportation traffic count data and MPO models.

Indicator Model: Greenhouse Gas Emissions. The EPA MOVES model uses fleet assumptions, modeled VMT and link-level volumes and speed data output by the travel model to estimate GHG and other mobile emissions.

Indicator Model: Water Quality. A nutrient loading model uses detailed land cover changes from the parcel-based land use model to identify changes in nutrient runoff experienced in each watershed. (Note: The current model estimates impacts only from Montgomery County and not from the entire Chesapeake Bay watershed.)

Indicator Model: Infrastructure Costs. An infrastructure cost model forecasts needs based on relationships between urban/rural development and the provision of infrastructure required for the forecast development pattern. The fiscal indicator model has been developed to reflect conditions and costs in Maryland.

While not part of the main analysis, a parcel-based model enabled the use of environmental indicator models of water quality by estimating land cover transitions at a detailed level. This is further described in Appendix D

5.2.2. Scenario Assumptions

Several components of the basic Chesapeake Megaregion Model noted above were enhanced to enable better responsiveness to the policy scenario of interest – high-energy prices. These changes are summarized below.

Economy. This indicated a dampening of economic growth nationally, which affected some sectors more than others leading to some changes in the industry mix within the megaregion.

Land Use. The model was also enhanced in all scenarios to enable a path-dependent land use method. This enabled only a portion of the new development occurring over the 20-plus year period to make (re)location decisions in any one year. This has been shown to be more realistic, allowing places to boom and bust, in response to more tightly coupled accessibilities. The national economic forecasts at 5-year intervals were allocated to counties, using the Lowry process noted above. In order to save time, the local allocation process from counties to zones was only done in the base and horizon year 2007 and 2030.

Auto Operating Cost (AOC) Sensitivity. Several aspects of the model were modified to improve sensitivity to auto operating cost. In the short distance person model these included: (1) trip generation rates varying with AOC, using elasticity's assessed by a Delphi panel of experts in travel demand modeling; indicating higher impact to discretionary travel and increases in trip chaining with more sensitivity found in lower incomes (Figure 43); (2) asserted Mode Choice model coefficients, incorporating a value of time variable in the utility function, enabling appropriate price response by income group; (3) re-specification of the accessibility measure

used in the mode choice and destination choice model to include auto operating cost in addition to traditional time and cost metrics. The accessibilities were also used in the megaregional economic post-processor. (4) Long distance person travel was assumed to be limited to a constant travel budget with, increased AOC leading to reduced number of trips and shorter travel distances.

Figure 43 Delphi Panel Trip Generation Rates
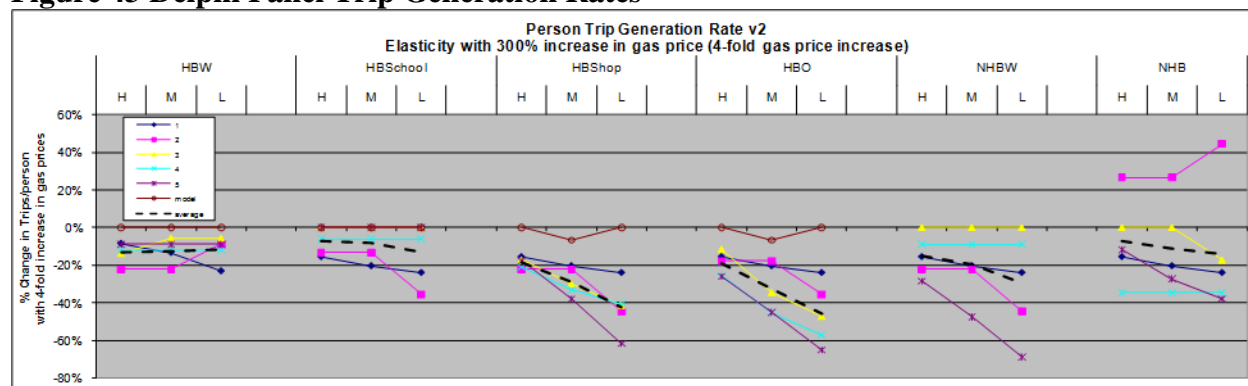
Note: H, M, L = High, Mid, Low income
Source: Delphi Panel Trip Generation Rate Elasticity Input Assumptions

Freight assumptions were not modified. Consistent with the literature, freight movements are less sensitive to costs. They tend to pass costs on to the customer as the price of doing business. They also are subject to longer-term contracts and investment decisions that make it more difficult to change modes and methods. Their higher value of time also makes them less susceptible to price fluctuations. Thus, while high fuel prices may affect the economy leading to changes in demand (i.e., commodity flows), the assumptions regarding how that freight demand would be fulfilled (mode, trip length, routing) were not assumed to change, other than facing a higher operating costs in routing decisions.

Fleet Mix. As noted in the scenario discussion the average fuel efficiency of vehicles was modified to reflect fleet turnover. This contributed to reduced GHG and auto operating costs.

After these adjustments, a limited validation of the model was completed. This included comparing the model's county VMT to HPMS data in both Maryland and Virginia. Additional calibration targets were available in Maryland including traffic and screenline counts covering the two major MPOs (Baltimore and Washington DC), as well as other locations across the state.

5.2.3. Framework Evolution

The analytical framework closely follows the generalized framework noted in Chapter 2.2. However, not all of the recommended components were exercised, and the tools are tailored to address specific issues within the Chesapeake Megaregion. The following special considerations are noted in the evolution of the Case Study analysis framework:

Model development tailored to Issues/context. A market analysis assessment of the CM revealed key issues, urban area strengths, industry clusters, and available data and models. The

resulting modeling framework has been designed with sophisticated long distance person and freight components as well as strong short distance person mode choice and pricing components given the megaregion's high transit usage and megaregional issues of interest. Upgrades to short distance models initially borrowed from MPOs has occurred based on needs identified in validation and sensitivity testing.

Integration with other Models/Data: Use of Baltimore Metro Council (BMC) model, built in CUBE was the basis for several short distance person and freight travel model components. Extensive MPO socio-economic input reconciliation (base and forecast year) as well as consistency checks were made to MPO intermediate and final outputs (i.e., trip rates, overall productions and attractions, trip length distributions, screenline traffic counts, and VMT). The framework made use of adjacent state DOT model data, national economic forecasts and federal data (Census, ES202, FHWA FAF and FHWA NHTS), reconciling different years and category definitions from the various datasets. The model was initially assembled with 2000 data (census), calibration year was 2007 (household survey data), and a forecast year of 2030 (consistent with MPOs). Model maintenance requires continued updates to incorporate new data and remain consistent with the megaregion's MPO models.

Vertical integration. The CM model is built as a multi-layer approach integrating a national with a megaregional model. This two-layer approach requires close integration of modules to pass on data required by each model, avoid double counting of aspects simulating, and develop smooth interfaces that facilitate integration even under extreme scenarios. In the CM model, Washington D.C. is subdivided at the local level into 85 zones (called MMZ or megaregional model zones). At the national level, the finest resolution used is counties. While such a pronounced geographic distinction in different model layers most likely is less relevant for urban models, this distinction is helpful when modeling larger study areas, such as a megaregion.

MPO Collaboration. The model is integrated with the two MPO models for Baltimore and Washington. Other megaregional MPOs may be included in the future. The existing integration works in two dimensions. On the one hand, aggregated results of MSTM are compared with MPO model results to ensure consistency across geographies, including number of trips generated, average trip length, mode split, and VMT by county. Agreement across models provides confidence in both the megaregion and the MPO models. In the interesting case where the two layers do not agree, it is insightful to understand why. For example, the megaregion model did not agree with the MPO models in terms of trip generation. After some research, the team found that these models were using different household travel surveys, and the impact of using different surveys could be traced down all the way from trip generation to assignment. Integrating in the other direction, model volumes from the Maryland Statewide Model (the starting point for the megaregion model) are planned to be fed into some of the MPO models as traffic at external stations. In contrast to simple traffic counts, which only provide the total number of vehicles crossing at a certain location, the MSTM volumes specify how many of these external trips are "through" trips (providing the entry and exit point to and from the MPO area), and how many trips have one trip end in the MPO. For scenarios, that may affect travel behavior long distance travel, such as widening the Capital Beltway, the MPOs may consider implementing this scenario in MSTM to provide updated external volumes under a given scenario.

Consistency between model's geographic layers. If trips are simulated at several geographic layers, special attention has to be given to minimize inconsistencies at the border between the layers. The CM model overcomes this inconsistency by applying different models at the more detailed megaregional zone system and to the coarser zone system at the national level. This way, both models can be calibrated to their respective zonal resolution, creating a more consistent result (e.g., combined trip length frequency distribution).

Tightness of component integration. The CM model uses a combination of level 1 and level 2 integrations, as noted in Section 2.2.7. While the economic and the land use model are stand-alone modules that are run consecutively (level 1), The long distance person model, the long distance truck model and the short distance truck model are built as one single module that runs efficiently without time-consuming reading and writing of intermediate results (level 2).

Input Consistency. Figure 44 provides a summary of various exogenous inputs to the model that are repeated at multiple locations. The color-coding of the text indicates inputs that are comparable. To ensure consistency, the same value was used in each instance where possible, such as the common fuel price and vehicle efficiency value used in the economic, land use, various transport models, and the air quality model. In other cases consistency checks were made to ensure the inputs were reasonably compatible, such as the base and future year socio-economic forecasts by county in the National Economic model, and the IMPLAN data used in the megaregional economic model. These were also compared to more official demographic forecasts by jurisdiction. Several other inputs are implicitly consistent as the values are obtained from upstream models, such as the tiered allocation of household control totals from the economic model through the land use model, used in the transport model and again in the indicator models.

Figure 44 Input Consistency
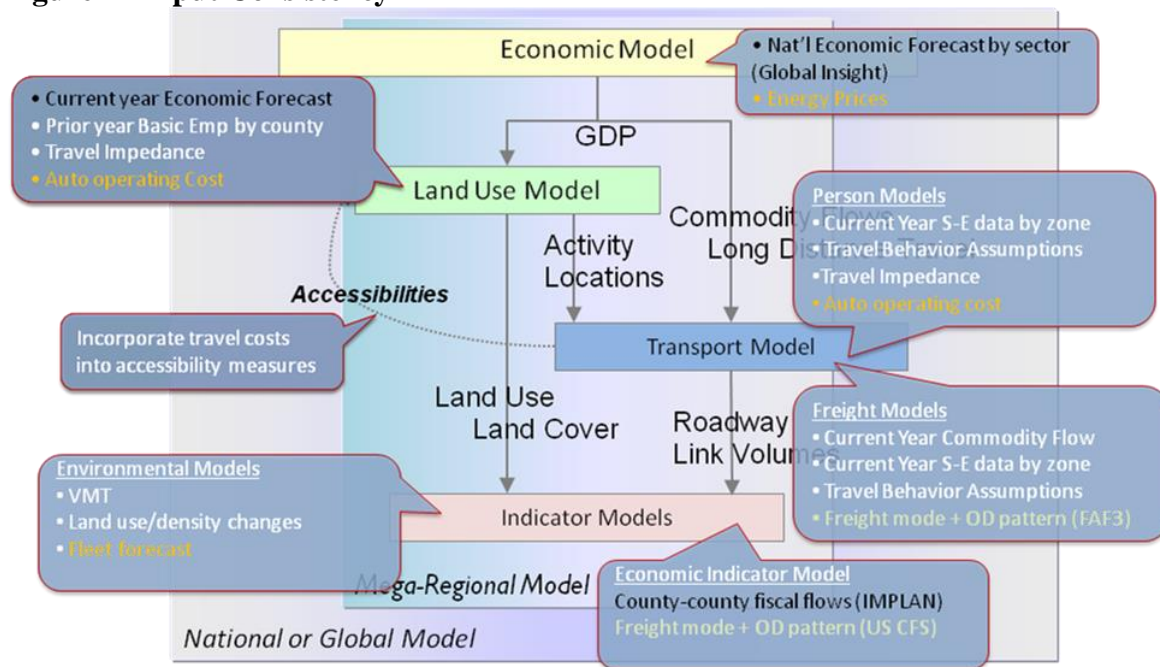
5.3. SCENARIO RESULTS

Two alternative price futures for 2030 have been discussed (Section 2.2), representing bookends of the impact to the Megaregion; a Price Spike in which petroleum prices stay steady for years and then rise very rapidly in a short period of time; and a slow Steady Price Rise to 2030. The Price Spike scenario retained the Reference scenario's economic and land use, taking all the impact in the transport sector. This section presents the full collection of findings on a high-energy future.

5.3.1. 2030 Reference Trend

In order to estimate future conditions a land use and transportation model was developed for the megaregion. The model was based on an expanded version of the Maryland Statewide Transportation Model (MSTM). The model covers all of Maryland and Delaware, the eastern part of Virginia, the District of Columbia and adjacent portions of Pennsylvania and West Virginia.

5.3.2. Household and Employment Change

The Chesapeake Megaregion consists of 5.7 million households in 2007 and 7.5million by 2030; employment increases from 9.3 million to 12.3 million by 2030, both roughly 30 percent over 23 years, at an annual compound average growth rate of 1.2 percent. This is the fastest growth rate in the Eastern Seaboard May want to move this section to an earlier location.

The percent change in households between 2007 and 2030 is shown in Figure 45. While households increase across the entire area, growth in the Baltimore, Washington and Wilmington areas can be observed, with significant growth also observed in Richmond.

Figure 45 Household Change 2007-2030
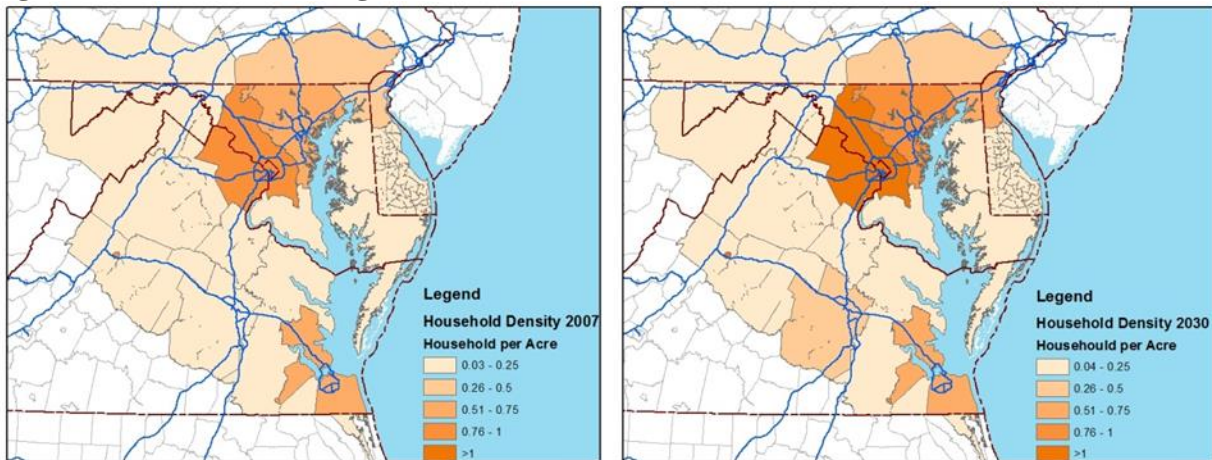
The employment increases in these megaregions are shown in Figure 46. Again, as with households, employment growth occurs in all parts of the megaregions but changes in

employment density are greatest in the Northeastern part of the megaregion and the southeast tidewater area of Virginia.
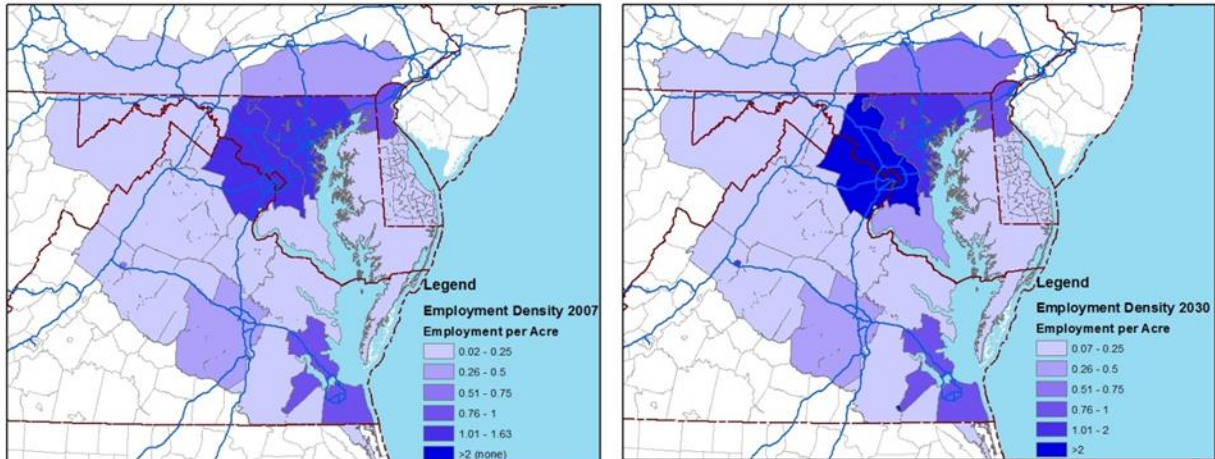
Figure 46 Employment Change 2007-2030

Figure 45-46 Source: Chesapeake Megaregion Model Outputs: 2007 Base and 2030 Reference scenarios.

Together, the shifts in household and employment location point to the need of plans at the megaregion level. These shifts span several states. Activities and land characteristics in one state can significantly influence land use in adjacent states.

5.3.3. Change in Travel

Highway Travel

Table 5 shows all trips by type within the Chesapeake Megaregion. Over 90 percent of the trips in the megaregion are for local auto travel. National trips are provided by the long distance model and cover trips with a length of 50 miles or more. Local trips are generated within the Chesapeake Megaregion and have a trips length of 50 miles or less. Although the national trips for truck and auto are longer in length, there are fewer of them.

Table 5 Megaregion Trips by Type (in Ten Thousand)

Vehicle	Class	Trips 2007	Trips 2030	Growth
Auto	I-I < 50 miles	6160.2	7448.1	21 %
	I-I > 50 miles	43.7	55.2	26 %
	I-E/E-I	38.6	48.3	25 %
Single unit truck	I-I < 50 miles	75.9	89.1	17 %
	I-I > 50 miles	0.5	0.6	26 %
	I-E/E-I	1.1	1.3	15 %
Multi-Unit truck	I-I < 50 miles	68.0	78.8	16 %
	I-I > 50 miles	0.8	0.9	23 %
	I-E/E-I	3.2	3.9	23 %
All Trucks	I-I < 50 miles	143.9	167.9	17 %
	I-I > 50 miles	1.2	1.5	24 %
	I-E/E-I	4.3	5.2	21 %
All Vehicles	I-I < 50 miles	6304.1	7615.9	21 %
	I-I > 50 miles	45.0	56.7	26 %
	I-E/E-I	42.9	53.5	25 %
Total		6392.0	7726.2	21 %

Classes	
I-I < 50 miles:	Both trip ends are within CM study area, trip length under 50 miles
I-I > 50 miles:	Both trip ends are within CM study area, trip length over 50 miles
I-E/E-I:	One trip end is within and one trip outside of CM study area, regardless of trip length

Source: Chesapeake Megaregion Model Outputs: 2007 Base and 2030 Reference scenarios.
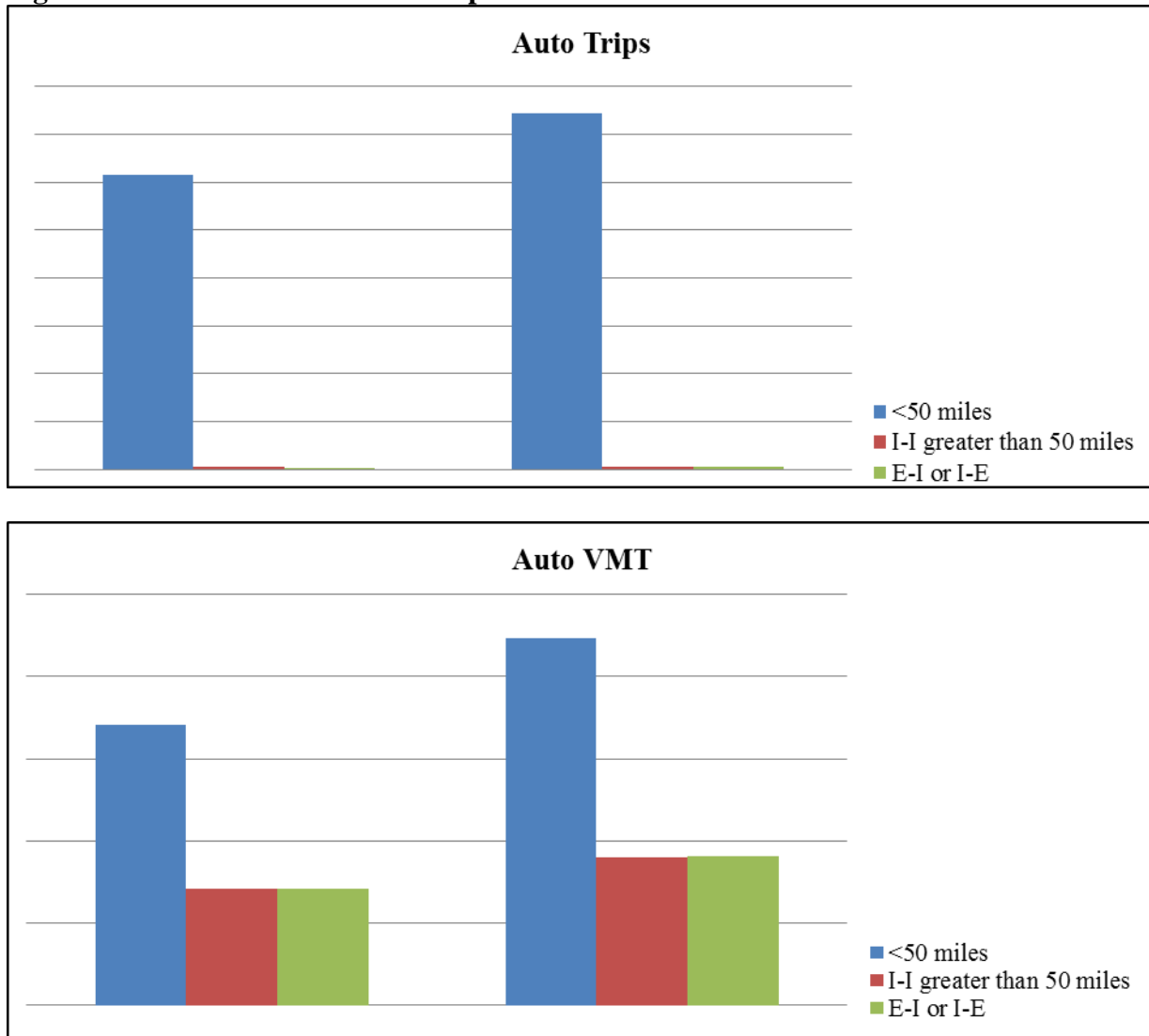
Figure 47 Travel Demand: Auto Trip

Figure 47 illustrates the growth in auto travel between 2007 and 2030, both in the number of trips and in VMT. The I-I trips identified in this figure have lengths greater than 50 miles but origins and destinations within the megaregion. External trips are those with either an origin or destination outside the megaregion. The figure shows that while the vast majority of trips are less than 50 miles, internal trips greater than 50 miles and external trips account for a very large proportion of VMT.

Figure 48 shows the growth in truck travel between 2007 and 2030. As with auto travel, short distance trips make up a very large portion of truck trips but internal trips greater than 50 miles and external trips account for a much larger proportion of truck VMT.

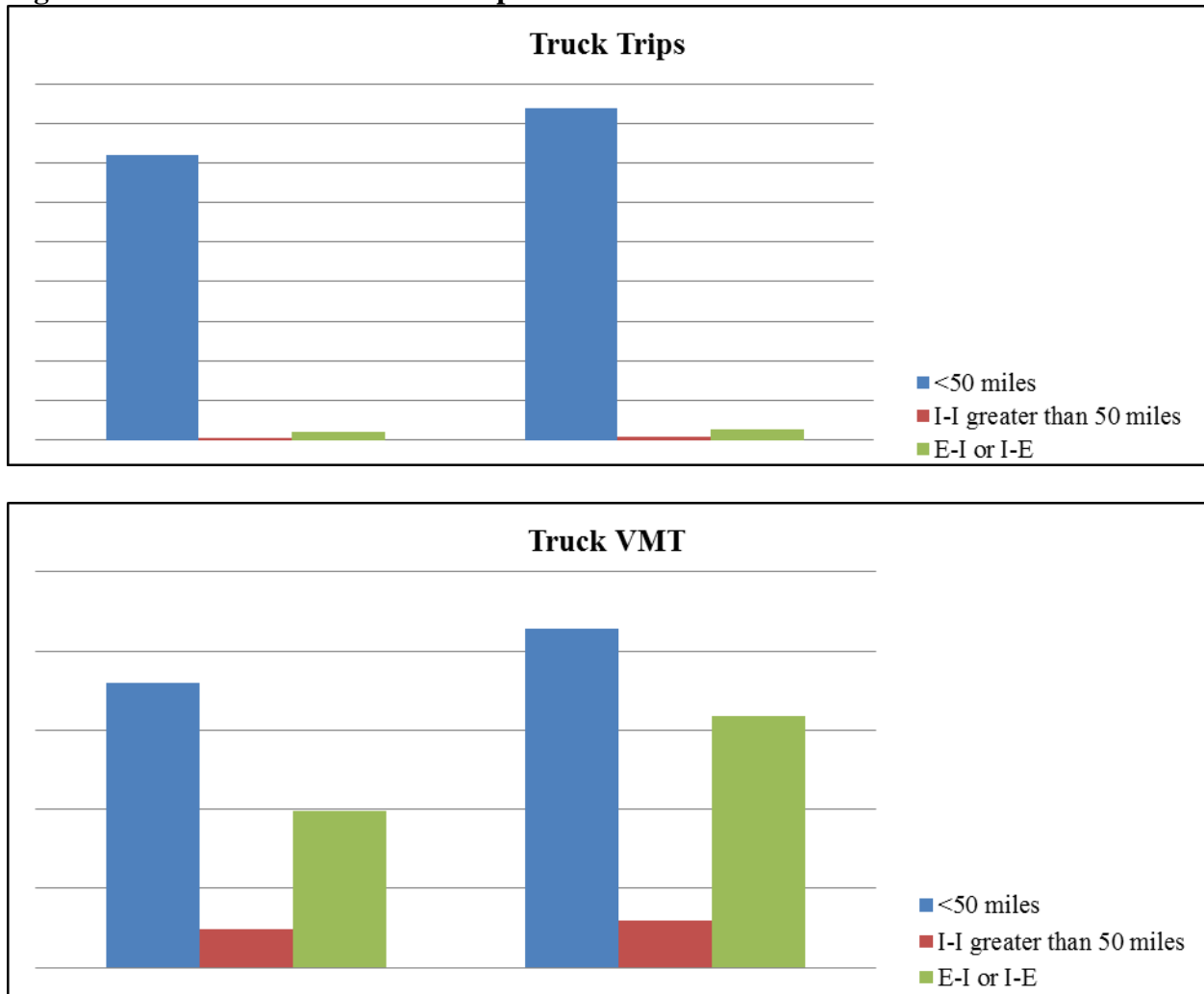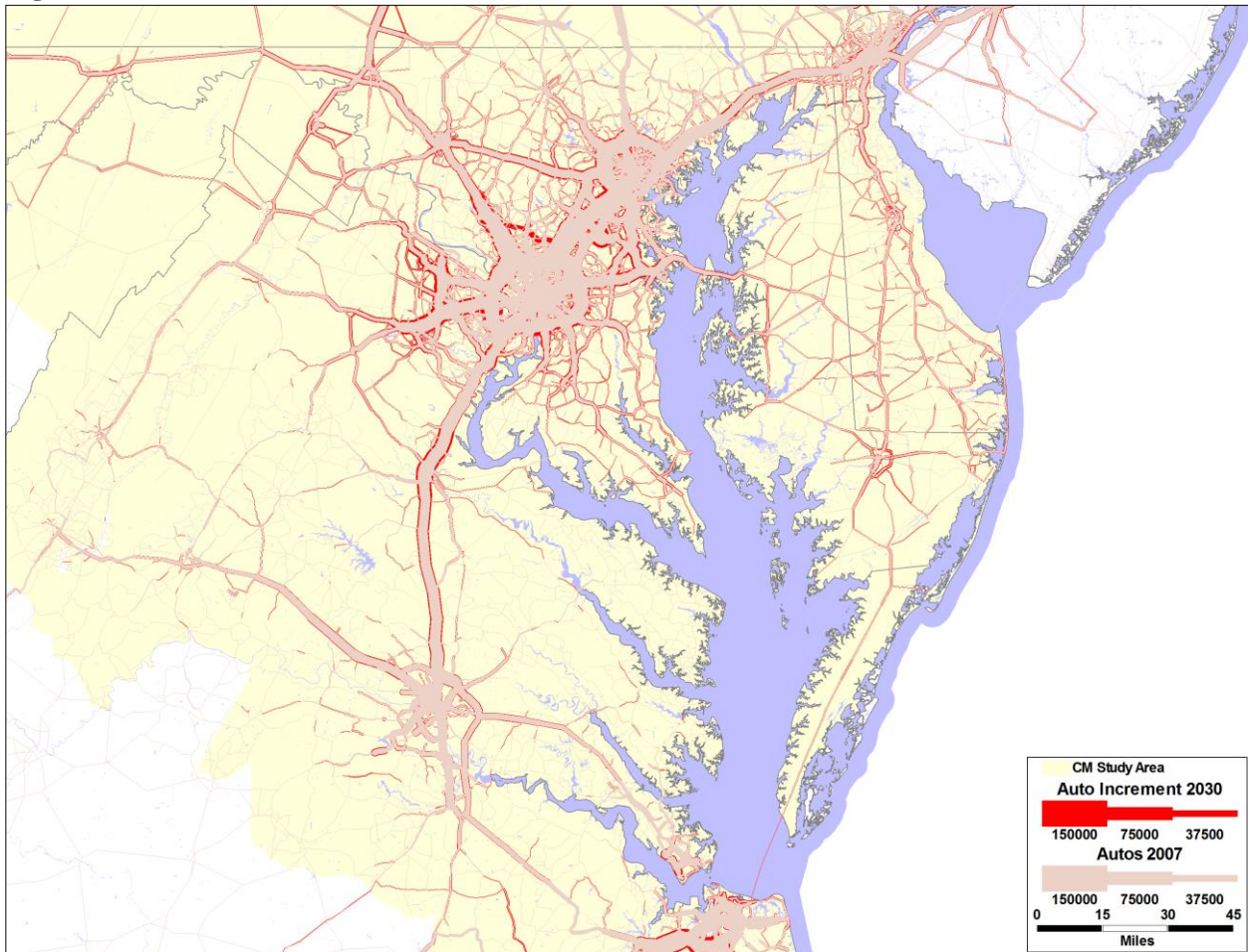**Figure 48 Travel Demand: Truck Trips and Truck VMT**

Figure 49 shows the volume of current auto travel on the highway network in light red and the expected growth in auto travel in 2030 in dark red. As shown, there will be significant travel volumes along the I-95/I-64 corridor in the future.

Figure 49 Growth of Auto Traffic on I-95 and I-64, 2007-2030

Source: Chesapeake Megaregion Model Outputs: 2007 Base and 2030 Reference scenarios.

Figure 50 the forecast volume to capacity ratios in 2030. Congestion in the Washington area and in the Baltimore-Washington corridor will witness significant growth. This congestion growth will affect movements up and down the entire I-95/I-64 corridor and could have a major impact on economic movements within the megaregion.

Figure 50 Demand/Capacity Ratio 2030
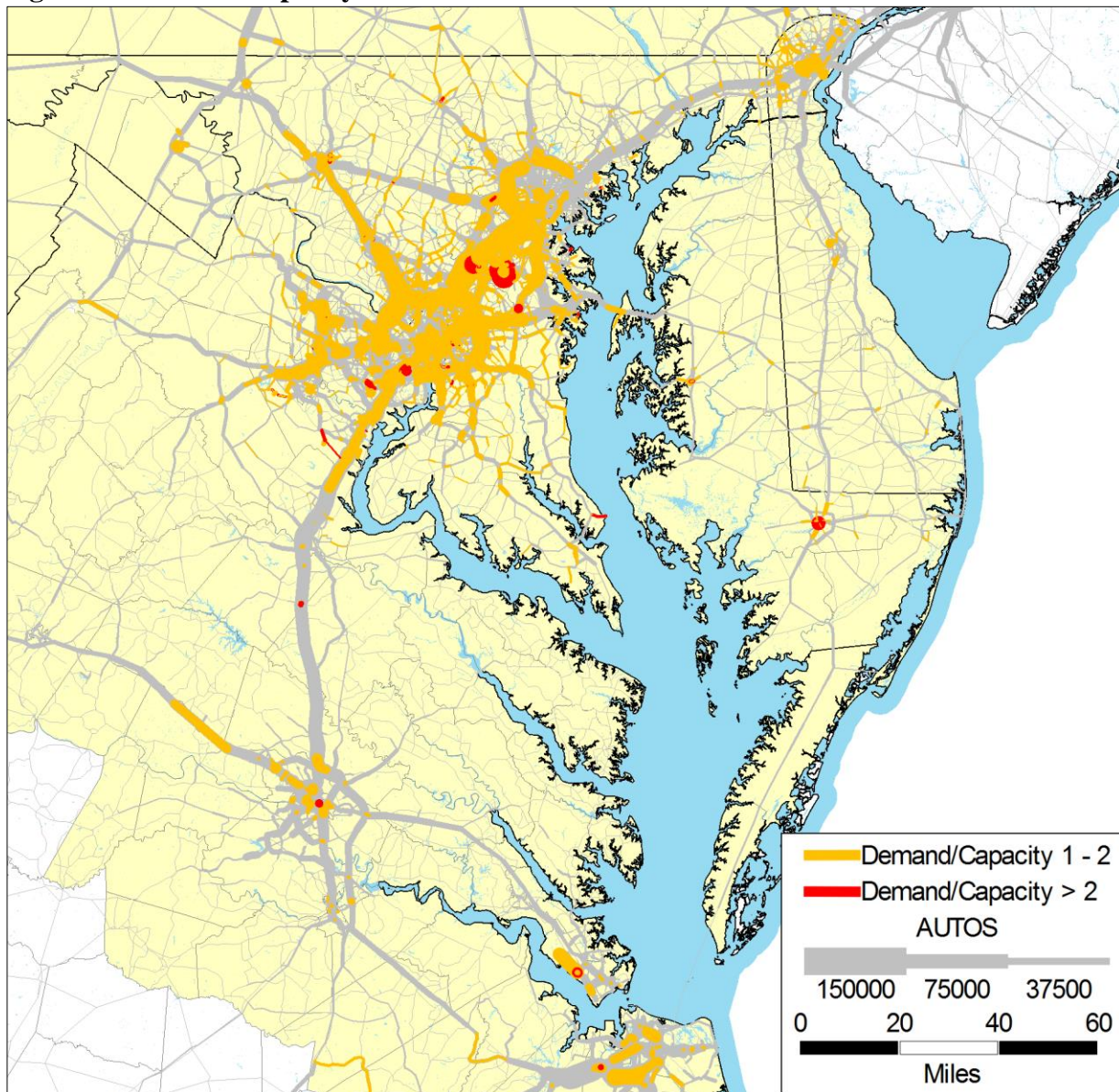
Source: Chesapeake Megaregion Model Outputs: 2007 Base and 2030 Reference scenarios.

Change in Goods Shipment Costs

Figure 51 represents the county pairs with the 25 highest generalized shipping expenditures in 2030. The expenditures include both time and vehicle operating cost, and the volume of goods shipped. The total expenditures therefore represent the weight of the shipments multiplied by the generalized cost. The figure highlights how the largest flows predominantly utilize I-95 and I-64. If either of these routes has a significant growth in congestion, the economic movements will be jeopardized. While there are east–west movements among the top 25, the bulk of the movements are in the north-south direction.

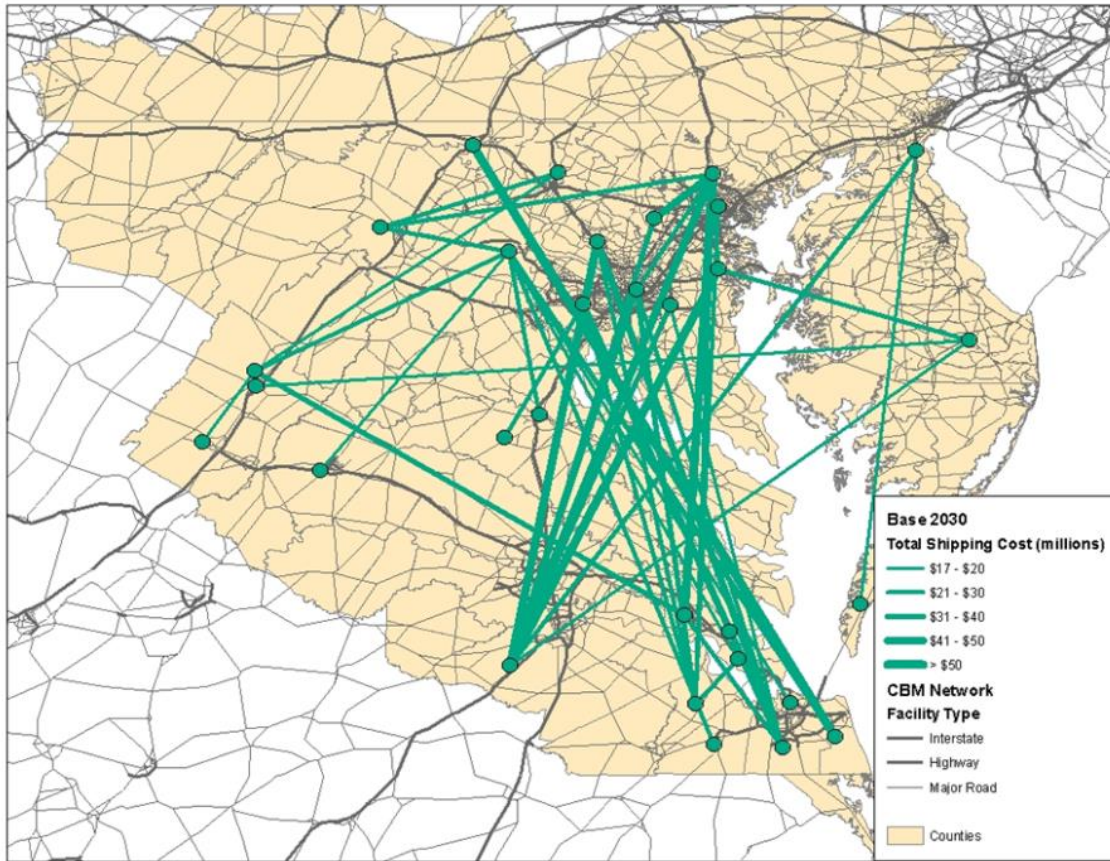**Figure 51 Goods Shipment Costs (Tons X Gen. Cost) 25 County Pairs with Highest Shipping Costs**
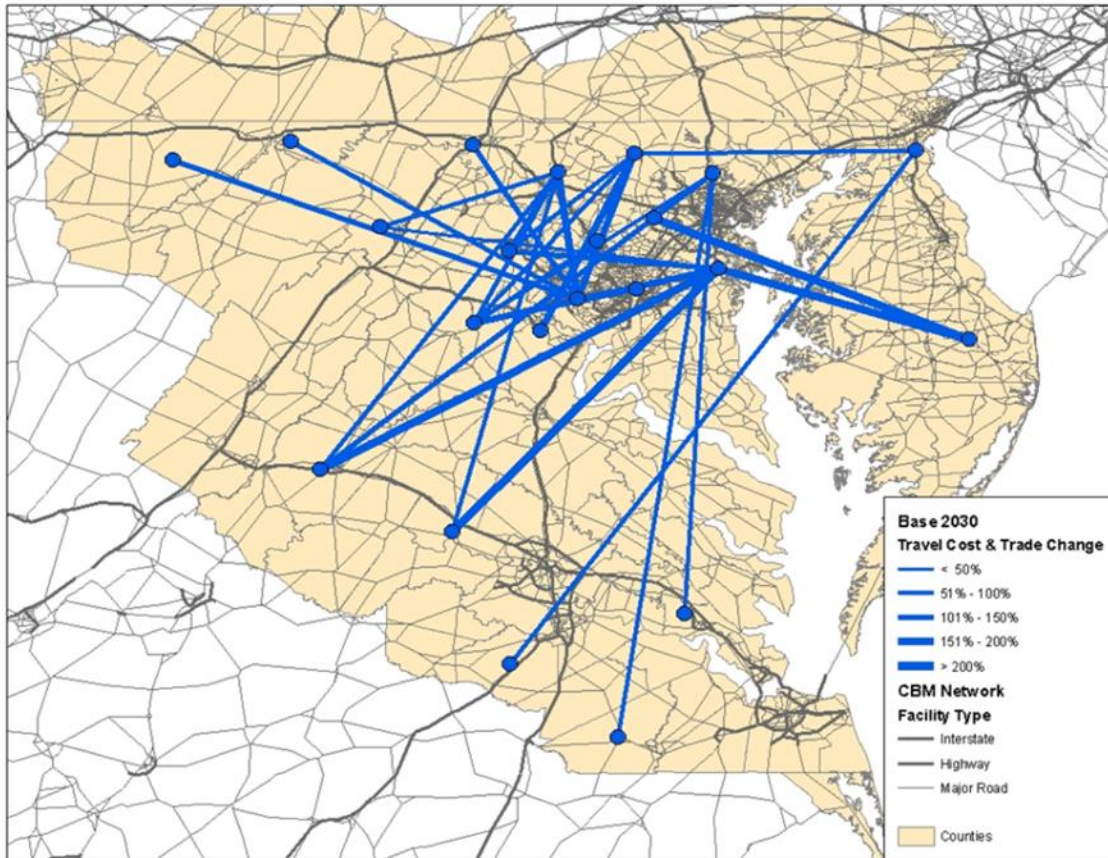

Source: Chesapeake Megaregion Model Outputs: 2007 Base and 2030 Reference scenarios.

Figure 52 represents the 25 county pairs with the largest increase in shipping expenditures in 2030 when compared to 2007. The increase in expenditures results from a combination of increased generalized travel cost and more goods being shipped. This demonstrates that in 2030, while most of the movements remain north – south, the greatest growth is in the east-west direction. The need for this east-west goods movement seems to be the result of the more dispersed growth of the 2030 reference scenario. However, much of the goods flow in the east-west direction that may not be well served by the current roadway network. In an area concerned with economic growth, this points to the need to view economic issue at a scale different from the MPO perspective. With the projected growth in congestion along I-95, particularly in the Washington, DC area, and along I-64, the ability of the transportation network to support projected economic changes will be called into question.

**Figure 52 Change of Good Shipment Costs 25 County Pairs with Largest Increase in Shipping Expenditures**

Source: Chesapeake Megaregion Model Outputs: 2007 Base and 2030 Reference scenarios.

5.3.4. Price Spike - Vulnerable Populations

Due to the suddenness of the assumed price spike, population and employment do not have sufficient time to shift location. As a result, several communities can be noted for their vulnerability to the price change. These include auto-dependent areas, which as Figure 53 shows are disproportionately located in the rural/exurban areas of the megaregion. Those megaregions have the highest tendency to drive alone, less ability to shift modes (carpooling, but limited transit), and their trip lengths are significantly longer on average. Due to sparse populations in rural areas, carpooling and transit are not as feasible as in urban areas. People in rural areas would need to rely primarily on shorter trips to respond to higher energy prices. Rural areas, with fewer alternatives, would thus be more vulnerable to higher fuel prices.

Figure 53 Vulnerable Communities – Auto dependent
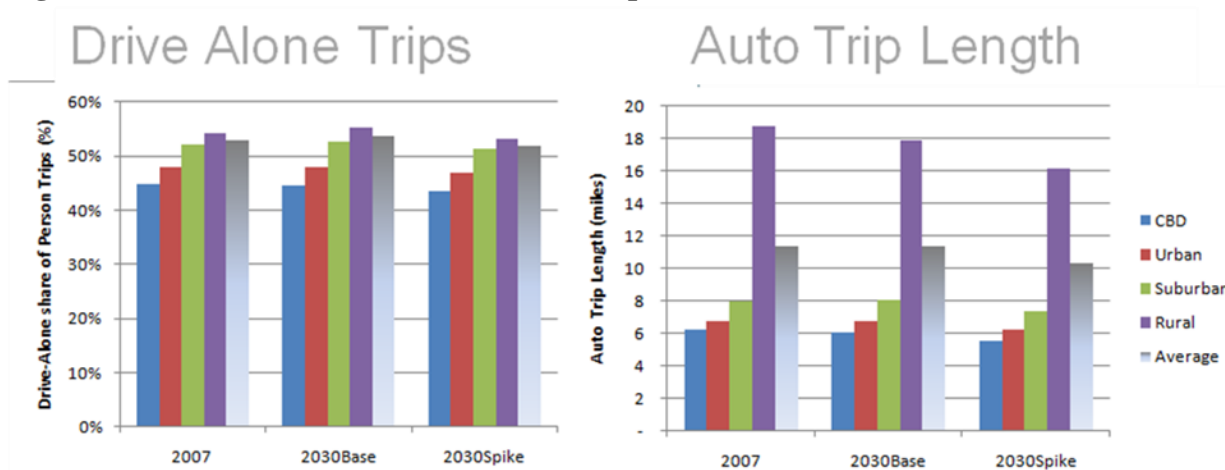
Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

A second community vulnerable to high-energy prices is lower income households. Travel costs constitute a larger share of their household budgets, allowing less flexibility in the face of higher energy costs. As shown in Figure 54, the share of these households in the CBD and Urban areas is high, but the bulk of the low-income households reside outside the urban areas with less access to transit options.

Figure 54 Vulnerable Communities – Low Income
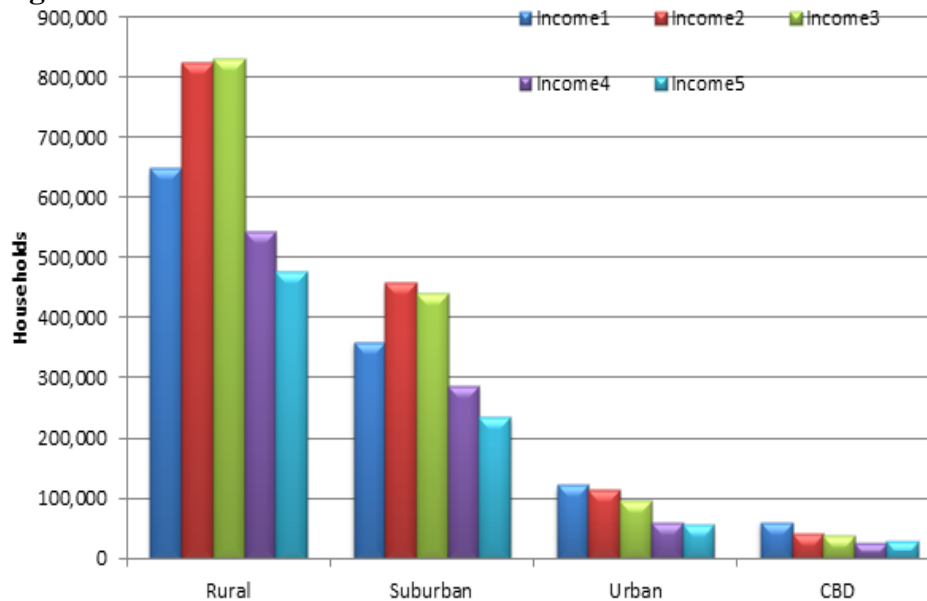
Source: CM 2030 Reference Scenario

Figure 55 Vulnerable Communities – Low Income
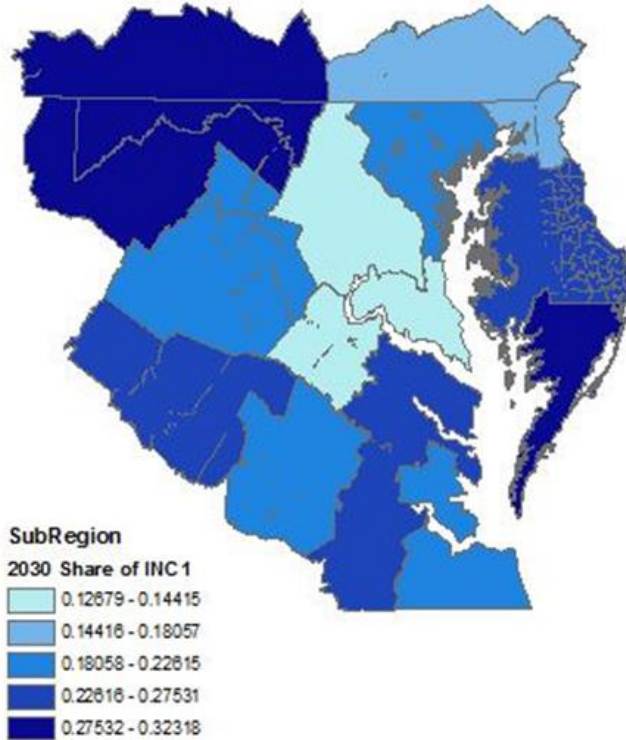
Source: CM 2030 Reference Scenario

These vulnerable communities, particularly those in rural areas, increased in the 2007-2030 Reference case, when auto operating costs were kept low by stable prices and greatly improved fuel efficiency (under federal CAFÉ standards).

5.3.5. Travel Demand – Significant VMT Reduction

Under our price spike scenario, an unexpected four-fold increase in the cost of fuel led to a significant reduction in vehicle miles traveled within the megaregion. As shown in Figure 56, the megaregion's travel was 25% below the 2030 Reference scenario, and even below that of the 2007 base year. The expansion of the rural/exurban VMT in the 2030 Reference scenario was reversed, with this group showing the largest decline.

Figure 56 Megaregion Vehicle Miles Traveled
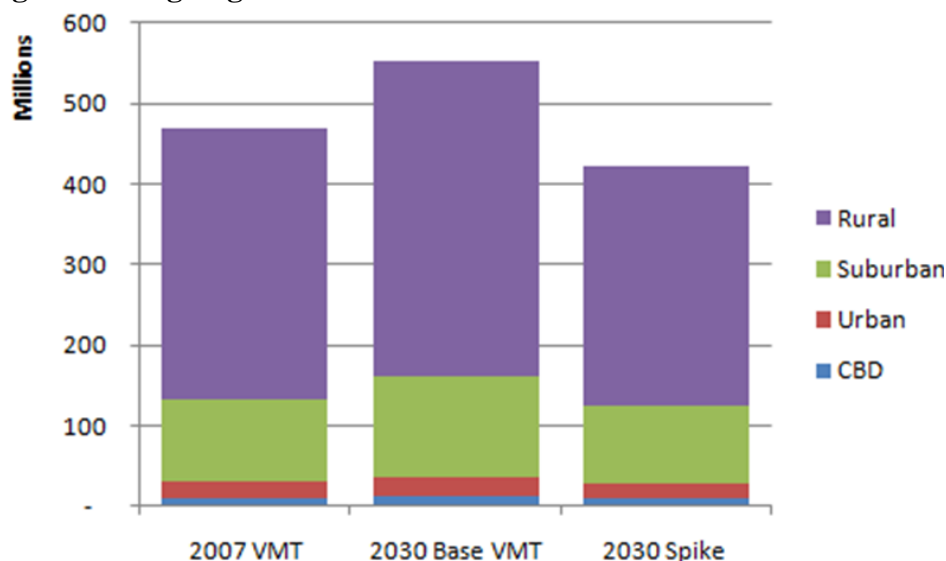
Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

The reduction in VMT was attributable to three sources:

Slightly Fewer Trips. A drop of 0.5% trips overall, with a higher 8% drop in long distance trips. As noted in the analysis method (Section 3.3), a Delphi panel of experts assisted in setting elasticity by trip purpose and income. However, the result had only limited impact on the overall number of trips generated.

Some Mode Shifts. Clearly the analysis found that where transit was available, ridership increased (22% transit ridership increase overall), while carpooling increased (7% overall) across the full megaregion. There was a corresponding reduction in drive alone (dropped by 13%). However, as with most megaregions, the auto dominates travel, and despite these increases in minor modes, the impact to the overall mode share was less pronounced, as shown in Figure 57. This applies in all area types, CBD, urban, suburban and rural. While a 22% increase in transit ridership may be small when compared to the impact on the highway network, an increase of this magnitude would strain the capacity of a transit operator to meet the increased demand.

Figure 57 Drive Alone Trips as a Percent of Total Trips, by Area Type
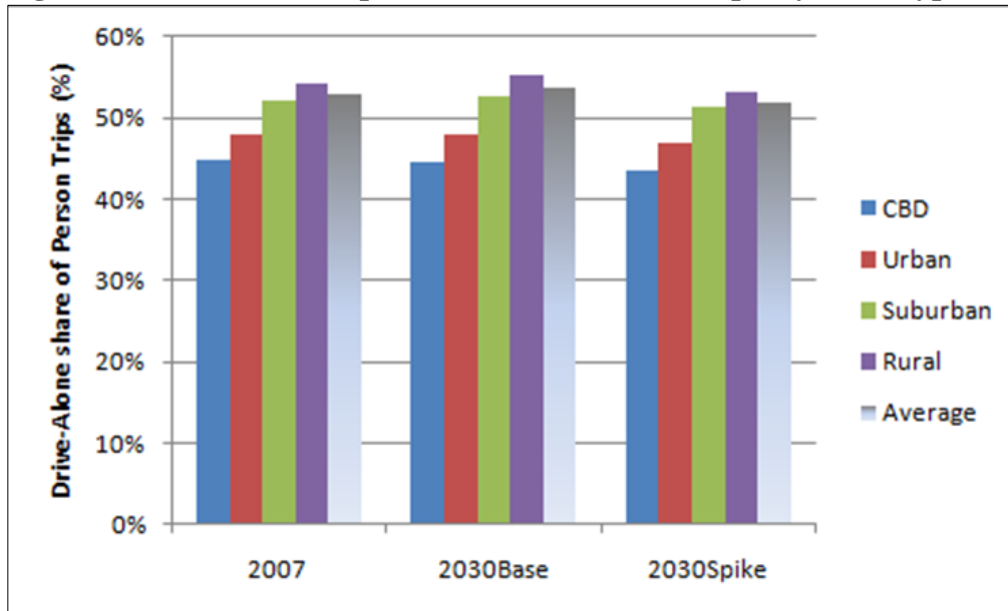
Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

Considerably Shorter Person Trips. The average auto-trip length declined by 9% on average throughout the megaregion and across all area types (Figure 58) and all trip purposes (Figure 59). This decline was most pronounced in rural areas with the least effect in CBD and urban areas. Examining the decrease in trip length by income and purpose (Table 6) highlights the greatest sensitivity to energy prices and the largest decrease in trip lengths occur for lower income groups. Trip purpose also influenced the response; with the greatest percentage, change in work trip length and least change in home based shop trips.
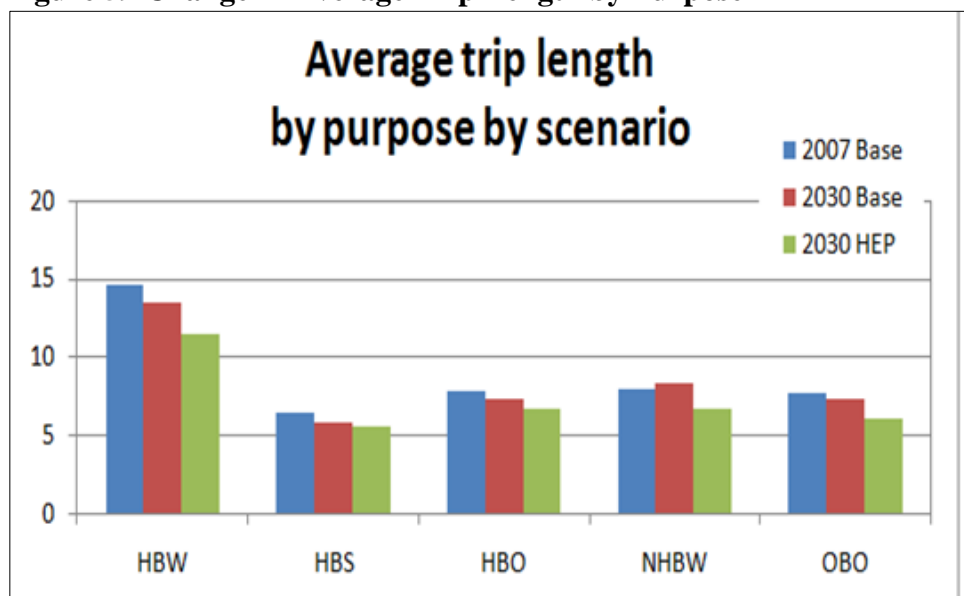
Figure 58 Change in Auto Trip Length by Area Type
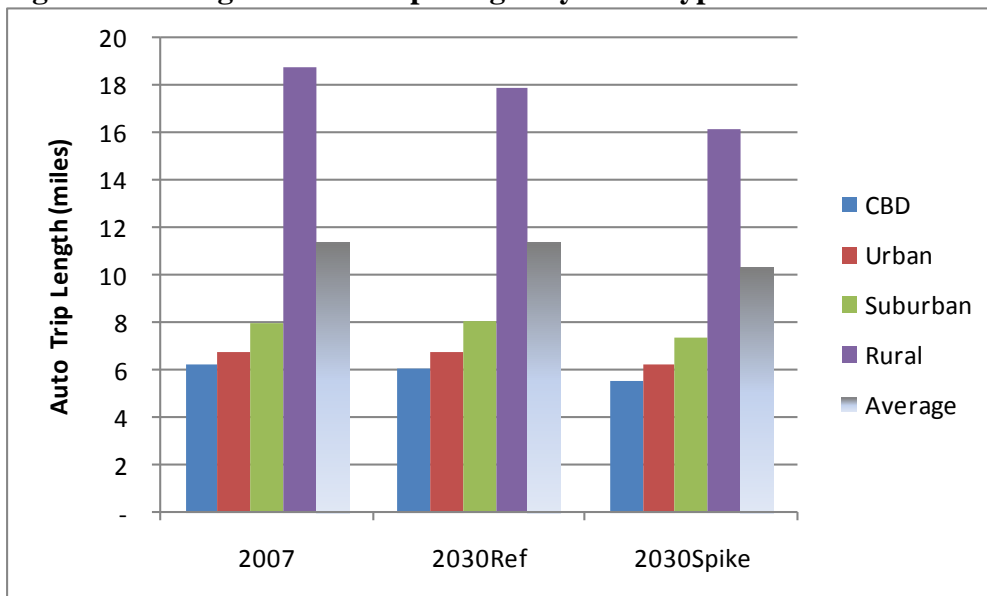
Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

Figure 59 Change in Average Trip Length by Purpose

Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

Table 6 Change in Average Trip Length by Income and Purpose – 2030 Reference Compared to Price Spike

Percent change in average trip length
2030 Reference compared to Price Spike

Purpose	Income Group				
	1	2	3	4	5
HBW	-22%	-21%	-17%	-13%	-9%
HBS	-7%	-5%	-4%	-3%	-2%
HBO	-12%	-11%	-8%	-7%	-5%

Source: 2030 Reference and Price Spike CM scenarios.

The reduction in VMT was largely the result of changes in travel patterns in personal vehicles. Freight, by design, showed little impact in the analysis. Higher energy prices have a different impact on freight than on passenger travel. Freight movements are derived from the FHWA FAF data and were assumed insensitive to changes in accessibility and auto operating cost. Therefore freight (and truck) movements may change routes but were not assumed to change destinations, leaving truck VMT largely unchanged.

As noted in the Framework methodology (Section 3.3), the analysis assumed a fixed economy and mode split (same truck-based demand), and consistent with literature assumed that the increased travel costs they faced would be largely passed onto customers as a cost of doing business. This also reflects the long term service contracts by freight movers that would be hard to change in the sudden Price Spike scenario in particular. The model assumes a much higher value of time for freight trips that also dampens the impact. As a result, the 2030 Price Spike scenario showed very stable trip lengths (shortened by 0.28 miles on average) and only a slight reduction in truck VMT (-0.5% overall)

5.3.6. Price Spike - Congestion Relief

The significant personal vehicle VMT reduction under the Price Spike scenario, led to an even more dramatic change in vehicle hours traveled (VHT), providing major congestion relief, at or below in many cases the 2007 base year (Figure 60). The large increase in VHT on collectors, the lowest level in the system, is attributed to collectors being close to capacity levels in the base year and being unable to absorb the additional traffic in 2030.

The congestion benefits are highlighted in Figure 61, where implied average speeds (VMT/VHT) drop by 20% overall, most pronounced in the non-urban areas. The key benefit of this congestion relief is to the freight movement across the Megaregion, now facing fewer delays and higher speeds, enabling them to take direct routes. Figure 62, shows increases and decreases in truck VMT by county. The counties in red are primarily located along the vital I-95 corridor. As travel decreases on the corridor due to increasing energy prices the corridor becomes less congested, allowing freight to take direct routes.

The positive impact of the Price Spike scenario on the megaregional economy is also supported by the economic post-processor results. Figure 62 illustrates the combined impact of changes in travel cost on commodity flows, between the 25 county pairs with the largest trade flow. In order to develop this information, the study assumed that the trade relationships between various employment sectors would remain the same in 2030 as in 2007. The 2030 flows were then multiplied by the generalized travel cost (time, tolls, and auto operating cost) from the 2030 Reference and Price Spike scenarios. The differences in these costs are shown. The results are somewhat non-intuitive. The initial assumption was that higher energy prices would adversely affect the economic flows between counties. However, as illustrated by the green lines in the figure, in many areas, particularly in urban areas and along I-95, the ability to make economic linkages improved due to congestion relief (drop in time portion of generalized cost). At the same time in rural areas, particularly to the west, the cost of making these linkages increased. In the urban areas, where higher energy prices led to shorter personal auto trips and a shift from auto to transit and carpooling, there is less congestion, faster movement and therefore lower travel "cost." Effectively the reduction in travel time compensates for the increase in operating cost. In rural areas, which do not have much congestion, there is little change in travel time and the generalized cost responds only to the increase in fuel cost.

Other studies with tour-based models have noted an additional impact of congestion relief. Logistics managers are able to add a few more stops to a drivers' daily route for the same number of work hours. Thus, while higher fuel prices may have a generally negative effect on a megaregion, they can provide a benefit to freight travel and thus the larger megaregion economy.

Figure 60 Vehicle Miles Traveled and Vehicle Hours Traveled
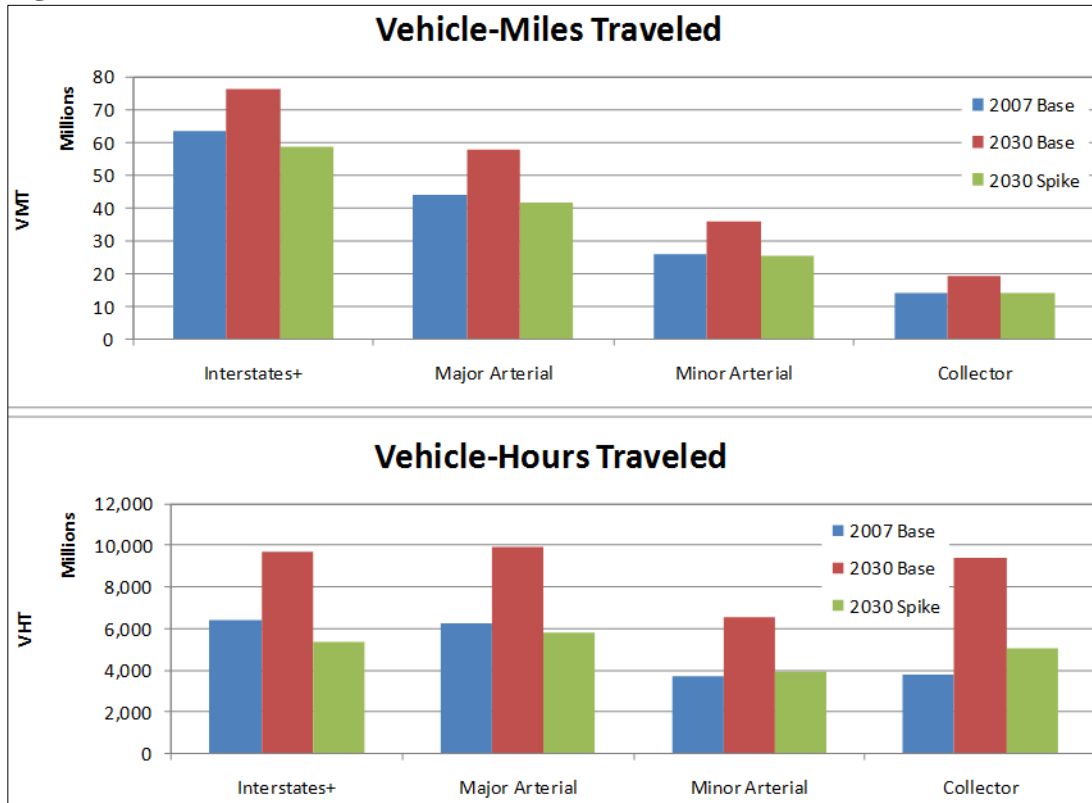
Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

Figure 61 Average Speed by Area Type
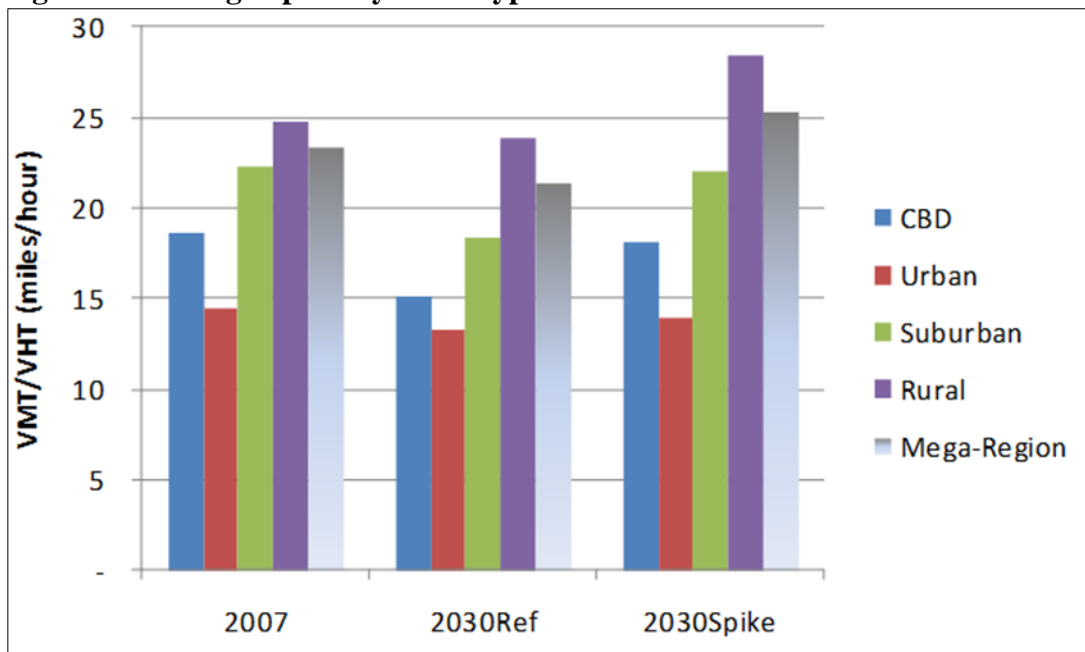
Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

Figure 62 Change in Percent of Travel Cost between County Pairs with Largest Activity
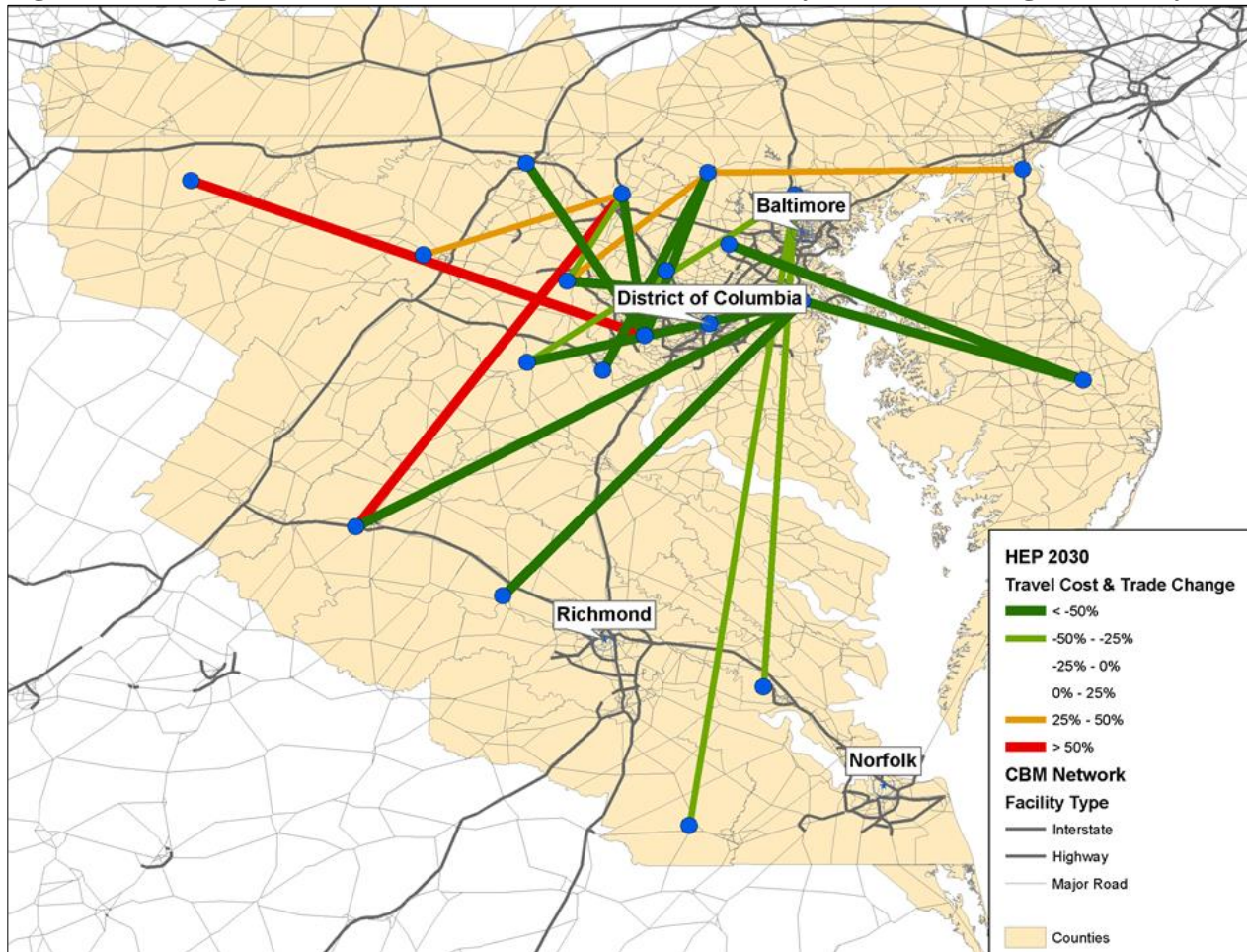
Source: 2030 Reference and Price Spike CM scenarios.

Figure 63 VMT Reduction by County – Auto & Truck Trips

Source: 2007 Base, 2030 Reference and Price Spike CM scenarios. Economic Post Processor

5.3.7. Indicators

Environmental Characteristics

Air Quality

The study used the MOVES mobile source emission model developed by EPA. Table 7 compares the 2007 emissions to the 2030 Reference and the 2030 Price Spike scenarios. Greenhouse gas emissions decline between 2007 and 2030 despite the megaregion's growth. The decline results from increased café standards for 2025. This assumes that the 2025 standards have affect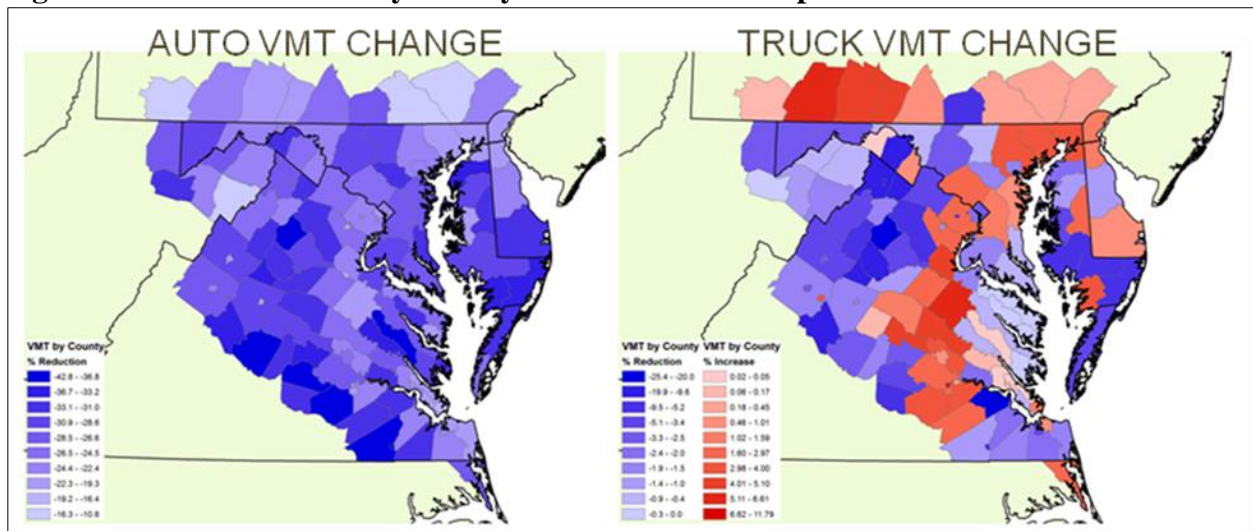ed most of the vehicle fleet. The price Spike scenario more than doubles the reduction from 2007 when compared to the 2007 base. This reduction is due to lower VMT combined with lowered congestion.

Table 7 Greenhouse Gas Emissions

	Auto mpg	Light truck mpg	Composite	VMT (Millions) (Auto + Truck)	CO_2 Metric Tons (millions)	Percent change
2007	27.4	20.8	24.4	468.92	180	
2030 Reference	54.5	35.4	41.8	551.59	154	-14%
2030 Price Spike	54.5	35.4	41.8	422.09	122	-32%

Source: 2007 Base, 2030 Reference and Price Spike CM scenarios.

The region's significant traffic both locally and as an east coast freight corridor contributes to energy use and climate change. Figure 64 maps the transportation-based GHG production across the region (by zone). While total travel will grow between now and 2030, air quality will improve due to the increased CAFÉ standards. Indeed, using the current fleet mix with 2030 forecast VMT, the GHG would increase by 12%, while under the expected CAFÉ fleet changes emissions are expected to drop below 2007 levels by 15% (compare with Table 6).

Figure 64 CM Air Quality - Greenhouse Gas Emissions Production
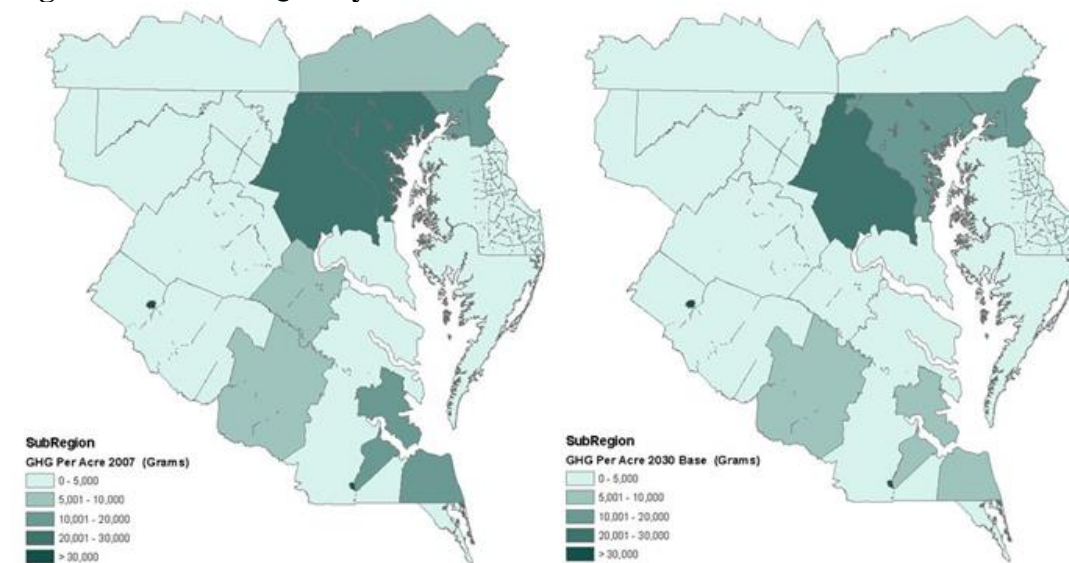
Source: 2007 Base & 2030 Reference CM scenarios.

Table 8 CM Air Quality – GHG Assumptions & Emission

	Fleet Assumptions			GHG Emissions	
Scenario	Cars mpg	Light Trucks mpg	Truck Share	Tons*	%Change
2007 Base Scenario	27.4	20.76	55%	180,474	
2030 Reference Scenario – Current CAFE STDS.	34.4	32.2	55%	201,516	12%
2030 Reference Scenario – New CAFE STDS.	54.45	35.4	55%	154,353	-14%
*includes LDV&HDV LDV – Light duty vehicles HDV – Heavy duty vehicle					

Source: 2007 Base & 2030 Reference CM scenarios.

Water Quality

The Chesapeake Bay and associated tributaries are more than a cultural focal point and recreational asset for the CM. The provision of clean water for residential, farming, fishing, and industry is of key importance to the region's economy, while the sea ports support the region's links to global markets.

Water quality in the Chesapeake Bay is estimated by surface runoff into the Bay. Surface runoff results from a combination of two factors, the type of soil in individual areas combined with the type of land use or land cover in the areas. This requires a very detailed land use and soils data base along with a forecast of land use in fine grained grid cells. A megaregion-wide application would necessitate a detailed land use and soils data base costly to develop. Due to limited resources the case study included a nutrient loading analysis for Montgomery County, Maryland only.

The effort modeled nutrient runoff into the bay. It highlighted that a major impact on water quality in the region is land use change/development as well as the often associated reduction in active agricultural lands. Agricultural land uses lead to a significant amount of nitrogen-heavy fertilizer runoff, a great detriment to water quality. The specific impacts are largely dependent on the actual use and soil type of the original land cover prior to the change. Even though runoff may increase with new development, nitrogen runoff may decrease due to shifting from agricultural land to other purposes. Figure 65 shows the rise in runoff with development. However, the significant loss of farmland due to development and economic forces result in a net decline in nutrient runoff.

Figure 65 2007-2030 Nutrient Loading Modeling Results
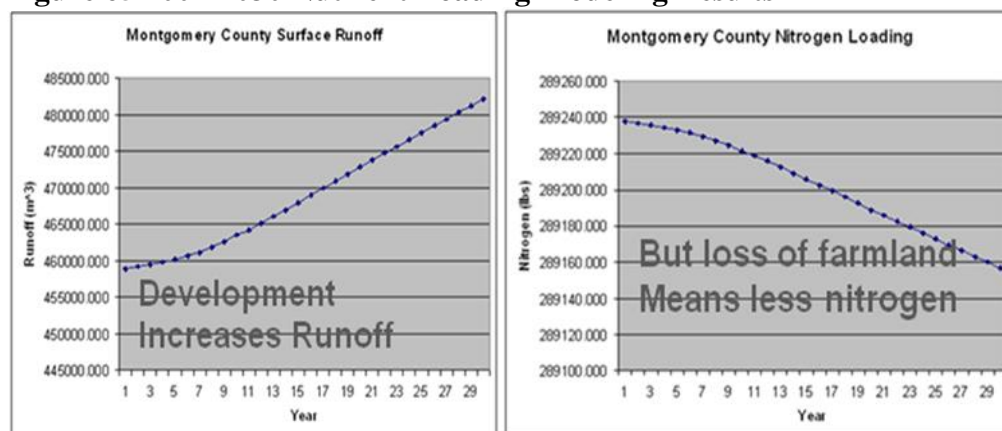
Source: 2007 & 2030 Montgomery County LEAM & Nutrient Loading Model

The nutrient loading model and the Montgomery county application are described in more detail in appendix D.

Fiscal Impact

The fiscal impact model estimates the capital costs associated with growth in population and employment. The model calculates the costs related to seven different types of local infrastructure. Roads, water, sewer, fire, and emergency medical services (EMS) are location-specific while schools, police, libraries and parks are a function of population and have a wider choice of location. The cost factors have been estimated for Maryland and are calculated on a county-by-county basis.

For the megaregion project, only the impacts of new road infrastructure were estimated. Attachment 2 provides a detailed description of the estimated cost of new road infrastructure.

The fiscal impact model analyzes the following costs:

Roads. The roads model assumes the provision of new capacity to maintain the existing road conditions. The basic assumption in the model is that the ratio of road density to population density will remain constant. However, in very rural areas with surplus highway capacity no improvements may be required. The model assumes that in urban areas there are slightly fewer lane miles per capita than in rural areas. In calculating the cost, the model assumes that additional lane miles will be added and does not account for areas allowing the highway level of service to decline. The model also does not account for changes in transit capacity.

Water and sewer. These costs differ by housing type and housing proximity. For example, multifamily dwellings generate lower costs than detached housing. The cost per square foot of housing type is then used to calculate the fiscal impact.

Fire and EMS. These costs are calculate by looking at the location of new housing or employment, then estimating how many new facilities would be needed to allow a five minute response time.

Schools, police, parks, libraries – These activities depend primarily on new population and are not location-specific. The costs are estimated by multiplying the costs per capita by the change in population.

The fiscal impact model is heavily location dependent for the first four categories. The spatial resolution of the megaregion model is not sufficiently disaggregate for detailed cost estimates. Nevertheless, the model provides order of magnitude cost estimates and can determine the relative costs of different alternatives. The fiscal impact model estimates what would be the capital costs of new infrastructure necessary to maintain the current levels of government service.

The model estimates costs necessary to maintain the current conditions. It does not forecast whether local areas will make the improvements necessary to maintain the conditions.

Figure 66 Fiscal Impact of Road Construction Necessary to Meet the Travel Demand Generated By Growth To 2030
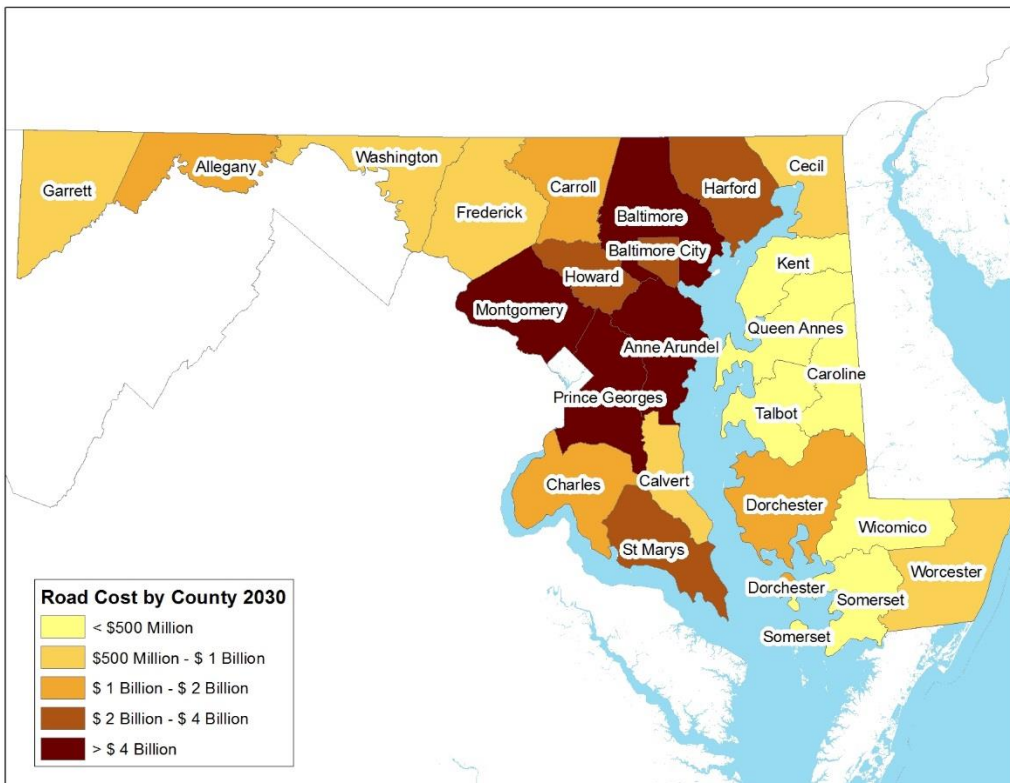
5.3.8. Conclusions

The case study analysis provides a wealth of information for a megaregion decision body and its resilience to a high-energy price future. Table 9 provides a summary of the results; both those taken directly from analysis (white cells) and those conjectured (shaded cells) based on our understanding of the modeling tools and work to date. Analysis showed that the more dispersed

land use pattern of the 2030 Base scenario led to an improvement in jobs-housing balance across the megaregion, but put residents in vulnerable locations that reduced their resilience to higher gas prices. The Price Spike scenario had a significant impact on travel, leading to shorter trips, more carpooling, and transit where available. This has the benefit of increasing speed and reducing congestion. In looking at the megaregional economy, the higher energy prices provided a positive aspect, allowing freight to move faster in more developed areas and facilitating economic linkages. Under this scenario, building on the benefits of the federal CAFÉ standards air quality further improves due to the decline in VMT.

Table 9 High Energy Price Case Study Results Summary

Performance Metric	2030 Base	Price Spike	(not modeled) Steady Price Rise
Economy			
Mega-Region-wide Economy	●	(●)	(●)
Household Growth	●	(O)	(●)
Regional Economy (impacts freight costs)	●●🔥	●&●	(●&●)
Land Use			
Compact/Clustered Growth	●	(●)	(●)
Jobs/housing balance	●●	(●●)	(●)
Vulnerable areas (low income, no transit)	●	(●)	(O)
Transportation			
VMT – Person (impacts to safety/health)	●	●●	(●)
VMT - Truck	●	●	(●)
Congestion/Speeds	●●🔥	●●	(●)
Environment			
Greenhouse Gas Emissions/Fuel Usage	●●	●●●	(●●)
Water Emissions	●	(●)	(●)
Fiscal Costs	●●	(●●)	(●)

Legend
●●
● Better
O   ┐ relative to 2007
●   Worse
●● ┘
🔥 = sleeping time bomb
() indicates not resulting from scenario analysis

Note: Direct analysis results are noted in white cells. Conjecture of the other measures is shown in shaded cells.

6. MEGAREGION BOARD – SUGGESTED RESPONSE

This project has identified the development of megaregions in the United States and throughout the world, developed a framework for the analysis of megaregion issues and demonstrated the application of the framework to a high-energy price case study in the Chesapeake Megaregion. From the literature review, we can see that the world is evolving into a series of megaregions, large-scale aggregations of population and employment spanning multiple metropolitan areas connected by economic relationships such labor and freight flows. These areas have their unique issues and the analytic framework described in Section 2 can form the basis for analyzing issues of particular concern. A Megaregion tends to have a broader view than just transportation, typically extending to economic, land use, environmental, and fiscal performance. The framework is designed to be flexible so it can be easily tailored to meet a megaregion's specific needs covering a wide range of situations.

In this case study, the generalized analysis framework was implemented in the Chesapeake Megaregion (CM). The case study assumes the existence of a megaregion board (MRB) which would have oversight on activities within the megaregion. The MRB would have concerns about economic development, transportation, housing, the environment and other issues, which play out at a scale larger than traditional urban regions. If such an entity existed, and the results of the case study were presented, several significant issues emerge which the MRB would want to address. These issues include the economy, freight, transportation and land use. The MRB would want to examine these issues from normal growth Reference scenario and alternative futures such as a Price Spike in energy prices.

The results of the case study also identify other factors, which would be significant to a MRB; the fact that the CM is tied together economically and that in addition to land use, transportation and the economy, the CM should address some policies at the megaregion level, such as emergency preparedness and the collective impact of individual local policies. The analysis framework can help to identify these policies as well as test their impact of implementing them in a coordinated or uncoordinated way across the jurisdictions within the megaregion.

The remainder of this section summarizes results of the CM future under a reference and high-energy price scenarios, and the need for analysis of emergency preparedness and other collective policies at the megaregion level.

6.1. REFERENCE – 2030

6.1.1. Economy and Freight

To understand the megaregion economy and freight movements, the impacts under continuation of trends must be examined; covering economic impacts both nationally as well was economic movements within the megaregion.

The national economy is projected to grow between the present day and 2030. At the same time, not all sectors of the economy grow evenly. An MRB would want to strengthen and support

those sectors, which are likely to grow and support a transition away from those sectors likely to decline. In addition, as shown in section 3.1, the megaregional characterization, the CM economy is closely knit. Significant economic flows occur between subareas of the megaregion, as measured by the value of shipments. The north south movements, particularly along I-95, are historically important and likely to grow, highlighting linkages along the full north-south spine of the megaregion. At the same time, with the dispersed location of employment growth as transport costs remain low, the need for east-west economic movements increases in the future. An MRB, with concern about the resiliency of the economy, would act to ensure that adequate transportation infrastructure exists in 2030 to support the growth in the east-west economy.

6.1.2. Land use and Transportation

In 2030, due to growth under assumed continuation of low transport costs and the challenge of absorbing more growth in the dense urban areas, more development occurs in suburban and rural areas. A proactive MRB would encourage the development of more compact communities by recommending changes in zoning and pricing to allow for higher density development and for mixed land use, allowing trips for multiple purposes to be satisfied within the same general area. Fewer and shorter auto trips work to preserve roadway capacity for higher economic functions such as freight movements.

The Baltimore-Washington area, with densities high enough to support transit, could benefit from additional transit service to help accommodate future growth. While multiple factors influence the location of employment, including accessibility, zoning, and public service provisions, a MRB would want to combine the knowledge of the likely employment changes with an understanding of which areas within the megaregion were most suitable for emerging residential and employment growth, as well as locating transport-dependent economic sectors near adequate roadway capacity over time. The fiscal tool can highlight the megaregions that can most efficiently accommodate growth, such as established urban areas where secondary road and school systems are already in place.

6.2. HIGH-ENERGY PRICE

6.2.1. Price Spike

A sudden energy price spike, in contrast, would likely have an immediate impact, primarily on travel but also on the economy.

Land use and Transportation

The travel effects of a energy price spike would hit hardest in the pocket-book of the megaregion's residents. In response, they can be expected to reduce the number of trips, change trip destinations to allow for shorter trips, make routes that are more direct and chaining of multiple trips, as well as increase the use of any alternative transportation options available to them, such as carpooling and transit services.

An MRB responding to increased energy prices, or anticipating such an increase proactively, could take several steps to ease this pain, while retaining the health, safety, and economic benefits of a significant drop in auto use. One such policy includes promoting more compact and mixed-use development centered on transit systems, which provide options for shorter trips, trips by transit, bike and walking. The simple act of moving children's activities closer to schools limits the need for travel and ability to serve such needs with alternate modes, such as biking or walking.

In the Baltimore-Washington area, where a wide range of transit options is available, the analysis showed a significant increase in transit ridership. In contrast, outside the Washington D.C. suburbs, urban areas in Virginia do not have a high level of transit service and did not see a comparable increase in transit usage. This makes residents more vulnerable to rising energy prices. A MRB could also encourage and support the development of alternative transportation options, so that when the higher energy prices hit these options are available. This includes investment in transit service, vanpool and ridesharing programs, and electric vehicle infrastructure such as charging stations in urban area and along major corridors such as I-95. Many of these options take a long lead-time to set up so an MRB would need to be proactive.

Telecommunication can also be a substitute for transportation. In many firms and across many occupations telecommuting is substituting for being at the worksite on a daily basis. An MRB could not only encourage the development of telecommuting policies but also support the deployment of the necessary infrastructure required to make telecommuting available to a larger portion of the population.

Economic Impact

The pinch that high-energy prices would have on vulnerable communities can have a pronounced effect on the megaregion's economy, especially if long term location and vehicle purchase decisions were made without the assurances of a high-energy price future. The drop in discretionary spending by households can be expected to impact industries, particularly those related to consumer goods.   Tourism will also likely be impacted. A MRB attempting to shore up the economy would look to implement policies to aid household budgets in general, or transport costs specifically such as providing more transportation options, as noted above.

Indeed, it speaks to equity issues within the megaregion as many lower middle-income households drive farther to work in less efficient cars and spend more on repairs than their wealthier neighbors. Thus, income inequality is deepened and exacerbated by high-energy prices. Reducing auto-operating cost is comparable to raising wages. Thus, a MRB might promote policies that reduce the amount of fuel used and/or the cost of owning or driving a car, thus reducing the impact of prices on household budgets and the economy.

For freight movements, the economic impact of a price spike would be mixed. The case study makes two assumptions with respect to freight. First, the cost of shipping is borne primarily by the shippers, not the freight carriers, reflecting long term contracts. Second, in manufacturing processes, particularly those requiring assembly of intermediate goods and shipment for final assembly, destinations cannot be easily be changed. The capital cost of establishing the origin

and destination facilities means that these locations are fixed in the short and intermediate term. Thus, freight trips must maintain their current patterns and modes.

Further, given that, the costs are not borne by the carriers and that the origins and destinations remain static, by lowering congestion the decrease in traffic can actually have a net benefit to freight and the economy.   This benefit can be particularly important for shipments, which are high value and /or time sensitive. They can move quickly without fearing being stuck in traffic.

Providing additional freight rail service, especially to communities not well served would be appropriate for planning for a sudden petroleum price rise. Currently freight trips of less than 400 miles travel primarily by truck, due to the cost of transferring to rail at the origin of the trip and at the final destination. In a very high price scenario, some rail trips would become more cost competitive and providing improved rail service would support the shift of mode.

6.2.2. Combined Policy Impacts

In the megaregion view, policies in one jurisdiction can have spillover effects on the rest of the megaregion. Individual areas can develop policies, which are optimal for one area but have negative effects on adjacent areas. Within the megaregion, with the linkages spanning many jurisdictions, the spillover effects can be wide ranging. For example, policies that attempt to foster economic development in one area may have the effect of removing development from another area. Further, policies that appear effective in a small area may actually have a negative effect on the entire megaregion. For example, policies in a community which require low density zoning for residential activity but allowing high density zoning for commercial activity may have the effect of generating additional travel but effectively 'exporting' that travel to neighboring jurisdictions.
A MRB, with tools similar to those used in the case study, would be able to analyze policies in isolation or combination, assuming either coordinated or uncoordinated policies, to determine their collective effect on the megaregion and on local jurisdictions.

6.3.   HOMELAND SECURITY

While this study did not address security issues directly, the threat is particularly severe in the Chesapeake Megaregion, home to the nation's capital and numerous military bases. It is clear that homeland security events could have a major impact on the CM with effects rippling elsewhere. For example, an evacuation from Washington, DC would likely tie up the entire I-95 corridor, affecting traffic flows from Philadelphia to Richmond and beyond. In the event of a natural disaster such as a severe hurricane, travel through the CM could be disrupted and it would be critical to move relief supplies in and people out. This type of planning can only be accomplished at the megaregion level, and the CM analysis tool would provide a great framework for such study

7. CONCLUSION – NEED FOR MEGAREGION VIEW

This project began with the goal of developing a framework for megaregional analysis and demonstrating an application of the framework to the CM. This was successfully completed. On a technical level, the project demonstrated that data from multiple sources can be combined to develop a multi-discipline, multi-level model and that the model can be applied on a large geographic scale encompassing a key US megaregion. On a policy level, the project demonstrated the impacts of high-energy prices on the economic, land use, transport, and environment of the megaregion as a whole as well as highlighting vulnerable communities and industries. The case study characterization and scenario analysis of highlighted how the CM is linked together economically and the value of analyzing a wide range of issues at the megaregion level.

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